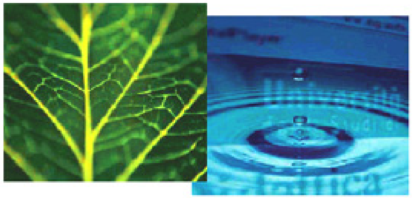
PhD Dissertation



International Doctorate School in Information and Communication Technologies

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MOBILE LEARNING: WIRELESS AND MOBILE TECHNOLOGIES IN EDUCATION

TOWARDS HOARDING CONTENT IN M-LEARNING CONTEXT

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Abstract

M-learning is a very new but rapidly expanding domain. Provoked by the fast advances of mobile technologies different applications and systems are developed continuously. Many new research topics are emerging in various areas, including technological issues, pedagogical and methodological ones, problems related to content, context, user interfaces, adaptation, etc.

The main goal of this thesis is to address the hoarding problem, which has been previously weakly explored but is a particularly important issue in the mobile domain and whose solution should be included in every system with a large quantity of data. For e-learning systems which are being converted/adapted for accessing the content through mobile devices it is generally the case – the learning material is often of big size, especially compared with the locally available memory of the device. Hoarding is the process of automatically selecting learning content which has to be prepared and pre-fetched on the mobile device's local memory for the following offline-session. Hoarding is highly needed in the m-learning context for two main reasons. On the first place is the demand to support what is called "any-time, any-place" education. This means that on the mobile device (e.g. a PDA – the kind of device often used in m-learning), which might be often disconnected from the Internet, the needed learning content should be available locally for allowing access during the offline periods. On the second place comes the desire to hide from the student the technologies that lie behind this ubiquitous learning. We would like to free the user from tedious operations of manual preparation and planning his/her next study session. Moreover often we cannot even count on the student's own judgment for his/her knowledge and future needs.

In order to attack the main problem the full context around the hoarding had to be constructed and is described throughout the thesis. In this sense the thesis appears to be multidisciplinary as it

treats also important questions about the construction and evaluation of an m-learning application. We have started with the choice of a concrete area for experimenting in mobile learning and hoarding. The chosen field was language learning and a prototype of a mobile language learning system was built. We discuss the general and concrete approaches to develop and build it. Motivations for our choices are given on every step. We describe in details the hoarding problem and the strategy to solve it with the goal to provide an efficient hoarding solution. Experimental results are presented, together with the practical experiences gathered from the interactions with the users.

Finally suggestions for improvements and further research issues are given.

Keywords
Mobile Learning; Hoarding; Offline Access to Learning Content; Disconnected Operations; Caching; Pre-fetching; General Approach; Concrete Techniques.

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Chapter 1

1. Introduction

E-learning is growing very fast and many Universities and companies are already supporting in some way an e-learning solution. There is now little doubt that the World Wide Web is a very successful educational medium. On the other hand wireless and mobile technologies have been developing very fast over the last few years. New devices and technological solutions appear on the market with great speed and the research and development communities are trying to find the best possible ways to use them. Small, relatively inexpensive devices like PDA (Personal Digital Assistant), smart phones and even the common nowadays cell phones, with already reasonably powerful characteristics, enable computational and data access while on the move. As a consequence, mobile applications are appearing in different fields, like commerce [4], healthcare [63] [64], tourism [32], etc.

The rush in the field of wireless and mobile technologies creates opportunity for new field of research also in the learning domain. Though the use of mobile devices for educational purposes was explored for the first time quite long time ago - in early 1970s in the Dynabook project [82], the term "mobile learning", or in short m-learning, can be more and more often found in the literature in the recent years. While 10 years ago only occasional papers could be found [11] in the last few years conferences and workshops are being organized on this topic.

The domain of mobile learning can include a wide variety of applications and new teaching and learning techniques (discussed in Section 2 – "M-Learning review of the literature"). The common criterion for entering in the mobile learning domain is to use a mobile computational device in some teaching and/or studying activities or education supporting services. As the m-learning domain is explored only in the recent years, many new research

topics are emerging in various areas, including technological issues, pedagogical and methodological ones, problems related to content and user interface adaptation, and etc. In their tries of finding the best way to apply mobile devices in education people are experimenting with different fields. Courses modules were created throughout different projects for people with numeracy and literacy problems, for kids, university students or working adults, for teachers, for studying computer science subjects, psychology or language learning. Mobile learning has been often considered as the next step in distance learning and as an integral part of any form of educational process of the future.

We analysed different ways to apply mobile devices for educational purposes. This led us to classifying services that are specific and should be provided by a general m-learning platform and later we concentrate on one of these services as a concrete problem to solve during the thesis. Namely this is the hoarding of content for offline usage.

1.2. The Problem and the Motivation

The problem we focus on is the one of supporting the access to web-based learning content from a PDA device during its periods of disconnection. Such offline periods may appear for different reasons – intentional (e.g. the available connection is too expensive for the user) or unintentional (e.g. lack of infrastructure at a given time and location). Such offline periods are frequent nowadays and our expectations are that the situation will not change much in the next years. During offline periods the user can only access materials located on the device's local memory. Mobile systems typically have a relatively small amount of memory, which is often not enough to store all available study material. In such a case a decision should be taken on which part of the material will be needed and has to be cached. Often we can not count on the user's own judgment of what he/she will need and prefetch it. Rather, in our opinion some sort of automatic prefetching would be desirable. The process of automatic selection

and caching of material to be used during offline periods is called "hoarding".

Related to hoarding terms are caching and pre-fetching. Though in similar contexts to ours sometimes they are used as synonyms of hoarding, they are more often used when considering online conditions and Web performance. Caching is a technique for keeping content that has been requested by one user available on the nearest server for a certain amount of time so other requestors can access it faster. Pre-fetching on the other hand is a technique which tries to guess what will be needed to the client in the near future, cache it and in this way improve the clients experience. In the context of mobile learning we prefer using the term hoarding which in some sense combines caching and pre-fetching. Different schemes of caching and pre-fetching are proposed and the goals are the reducing of network traffic, minimizing the access latency, bottlenecks, servers' workload, etc. in the WWW world. Although the goal of hoarding content for offline usage is shifted a little from the one of Web caching, some of the techniques can be reused. However while in the online case one can balance between the accuracy of the cached set and the added traffic, in the situation we consider much higher accuracy is required and the added limitation is the memory availability. The learning scenario has characteristics that expose some additional information to be considered and thereby possibility to provide an efficient solution.

Despite of its importance this issue has not been addressed seriously up to now. Moreover, people have avoided facing this problem for years, saying that mobile devices' characteristics are continuously growing and soon a fast Internet connection will always be available. In the fall of 2000 Clark Quinn [80] wrote:

> "The vision of mobile computing is that of portable (even wearable) computation: rich interactivity, total connectivity, and powerful processing - a small device that is always networked, allowing easy input through pens and/or speech or even a keyboard when necessary (though it may be something completely different like a

> chord keyboard), and the ability to see high resolution images and hear quality sound."

We point your attention to the words "*portable*", "*total connectivity*" and "*always networked*". About five years later in 2005 such situation is still not reached, which for mobile users means that learning content is not accessible during periods of disconnection. We can still see the neglecting of the need to support offline delivery of learning material to users equipped with mobile devices. An example can be seen in [22] where, talking about ubiquitous learning environment and discussing the u-learning architecture no offline access is considered to be supported. The argumentation from Des Casey is that:

> "… it is reasonable to assume that GPRS and similar connection charges will progressively reduce in the coming years…"

Though we also agree that this will sooner or later become true, the current situation is not as we would like it to be. The problem of mobile devices being often offline exists! First, we can not assume that learners will equip themselves with the top technologies. The devices have really become mobile, in the sense of light, small and powerful, for impressively short periods of time and though there are quite a lot of technological ways to connect to the Internet, through WAP, GPRS, Wi-Fi, etc. still users have long periods of disconnection. Second, the always growing need of 'more space' can be seen also with desktop PCs. Once more space is available the user starts using it and will soon need more. As it is true for the compression technologies and for web-content caching that they will be always needed, it will be the same with the mobile devices and hoarding. Once we can put on the devices memory all the text-data we will want to put video also; once we can put video we will want higher quality that needs even more space, etc.

All these led us to the conclusion that hoarding should be considered whenever we want to develop an efficient real-world mobile learning system.

1.3. Contributions of the Thesis

The main goal of this thesis is to address the hoarding problem, which has been previously weakly explored but is a particularly important issue in the mobile domain and whose solution should be included in every system with a large quantity of data.

In order to attack the main problem the full context around hoarding had to be constructed and is described throughout the thesis. In this sense the thesis appears to be multidisciplinary as it treats also important questions about the construction and evaluation of an m-learning application. We have started with the choice of a concrete area for experimenting in mobile learning and hoarding. The chosen field was language learning and a prototype of a mobile language learning system was built. We discuss the general and concrete approaches to develop and build it. Motivations for our choices are given at every step. We describe in detail the hoarding problem and the strategy to solve it, with the goal to provide an efficient hoarding solution. Experimental results are presented, together with the practical experiences gathered from interactions with the users.

Here, the main points of contribution are listed. It should be mentioned that a great part of this thesis has appeared in different articles, published in international journals and conferences. The full list up to date is given as an appendix at the end of the manuscript.

- The first contribution of the thesis is the *drawing of the attention of the researchers and developers in the mobile learning domain to the importance of the hoarding problem*. As we discuss above, in our opinion this is an important issue in the real world and, as will be discussed throughout the thesis, it appeared to be not a trivial research issue. However as the problem was often ignored we think it is essential to stress its existence.

- The main goal of the thesis was to explore the hoarding problem. In this context we *propose a general approach for hoarding* (Section 4) that explores the integration of a couple of

different techniques into the hoarding algorithm. Our bottom-up approach to hoarding starts from the special case of a real world system, and is based on a set of general principles described in section 3.1.5. Our ultimate goal was however to provide a general strategy that can be also used in different mobile learning systems with a relatively big learning materials base and that need to access it during offline periods. We describe ideas of the possible approaches, what algorithms are appropriate and in what cases. We analyse how different parameters that emerge from our work should be tuned by researchers and developers of mobile learning solutions. All discussed would help to those who also want to automatically decide what part of the learning content the user will need in the next offline period and do the caching.

- As mentioned earlier, the domain of mobile learning is quite young and researchers are wandering between one problem and another and between different technological solutions. One of the contributions during this thesis to the research community was the survey of the state-of-the-art and ongoing projects (partially Section 2) which was done at a very early stage of this work. It provides *guidelines for successful development of mobile learning applications and directions for further contributions in the field* (see 2.3). The overview, published in one of the biggest e-learning conferences (E-Learn'03), was further cited and used as a reference point by multiple researchers.

- Based on the above mentioned survey *we proposed a general architecture for mobile e-learning* (Section 3.1.5). It explores the possibilities to extend e-learning system so as to provide services to mobile devices. These services range from distribution of didactic material to support of location-aware services to mobile users equipped with variety of devices. The proposed architecture is general and would be able to provide all possible services from an e-learning platform plus additional services only for mobile users. At the same time it is extensible for the new generation of devices.

- Based on the proposed general architecture and general approach to hoarding we developed a working *'proof-of-concept' system*, called Mobile ELDIT. The system was designed after analysing various suggestions from researchers in the field of mobile learning (described in the state-of-the-art section) and comprising with all the findings, so that it should be useful and a pleasure to work with. The newly developed Mobile ELDIT is a version of ELDIT [30], an innovative system for online learning of the German and Italian languages and it allows the users to access a subset of the ELDIT learning materials from mobile devices (namely PDAs). Later in this document we will show our results at different stages of our research on hoarding using the Mobile ELDIT system and experiments done with it. These results have the goal not only to confirm that the proposed general approach to hoarding works in practice, but also to show how the different techniques and parameters influence its work. Also users' experiences and feedback gave us important indications for the successful m-learning future.

- Our originally developed as a 'proof-of-concept' system, called Mobile ELDIT, was successfully used initially by a dozen self-guided learners. It appeared to be a *viable and complete real-world mobile learning system*, based on an innovative language learning system. Some of our first users were using m-ELDIT as an additional tool in their preparation for the exam of bilingualism. They successfully passed the exam and report that studying with the PDA really helped them in it. Mobile ELDIT was successfully introduced in a Miltimedia Language Centre in Merano, Italy for few months in 2005. Additionally, since the beginning of 2006, Mobile ELDIT has been used in a school environment for teacher guided activities. In collaboration with L'Istituto Svizzero di Pedagogia per la Formazione Professionale a class of 10 students used the system for the period of 4 weeks. Both teachers and pupils report that the system integrates well with their study process and are eager to continue using it in the future.

- Last but not least, though not directly connected to the hoarding problem, we should also mention the outcomes of *a survey aiming to determine the readiness of University students for mobile learning* that was carried out involving more than 600 Italian and 200 Bulgarian participants (Section 3.1). The survey led to very interesting and important deductions about parameters that influence students' attitude to mobile learning in general and their preferences for prospective services that should be supported at their university.

1.4. Thesis Organization

The thesis organization basically reflects the process of our work over time. As illustrated above the thesis is directed towards solving the hoarding problem. In order to research possible solutions the full context around hoarding had to be reproduced. Thus, the thesis treats a number of questions and looks at different aspects of the whole process of designing and developing an innovative mobile learning system. The work started from scratch and advanced step-by-step, requiring decisions to be taken at every phase. This leads to the logical structure of the thesis chapters that describe these consecutive steps, their different aspects, the problems that we run into and their solutions, as they came and followed in time. For this reason also conclusions and related work are given immediately after each separate subtopic.

The thesis manuscript is organized as follows:

Chapter 2 (the following section) presents a review of the research in the Mobile Learning domain, as it was done in the beginning of the thesis in the end of 2002. It contains examples and descriptions of m-learning projects and systems, classified by their research aims. In this manuscript this review of the literature has not been much updated on purpose – for showing the situation of the m-learning domain at the time the deductions and the guidelines were made. However its classification structure and

deductions are valid also for the activities and projects of the forthcoming years of research in the field up to now. In this section we give the definition we adopted and used throughout the thesis, discuss the accumulated from previous work conclusions and guidelines which were considered during the rest of the work.

Chapter 3 presents and discusses the research context.

The first part (section 3.1) is dedicated to the results of the survey performed in order to determine the readiness of University students for accepting mobile learning in their everyday life and curriculum. Though such surveys have been performed in other countries by different researchers, a review of similar studies showed that the results might widely vary. We were seeking to reveal the situation in our environment so an online survey was performed with Italian and Bulgarian university students.

The second part of section 3 (3.2) is dedicated to the general mobile learning architecture that we proposed and according to which we developed further our Mobile ELDIT system that contains the hoarding subsystem.

In 3.3 is presented the real-world system that was developed during the thesis as a proof-of-concept of the theoretical deductions that we have made and for experimenting with different hoarding strategies. Here we explain in some details the particularities of the ELDIT system, part of which became our Mobile EDLIT. We explain how and why we chose ELDIT, describe the design principles we followed for the development and the practical solutions chosen.

Chapter 4 discusses the hoarding problem and the general approach to solve it. This section starts with the formalized algorithm that has to be followed for successful hoarding. It is followed by detailed step-by-step discussion of different subprocesses of the hoarding.

Chapter 5 is dedicated to the contextualization of the solution, i.e. to the concrete implementation of the general approach described above into our Mobile ELDIT system. Experimental out-

comes that we obtained include results from the hoarding in various stages and explanations about the differences of the steps taken. Interesting observations over the users together with their experiences, impressions and opinion were collected via interviews and questionnaires. Though they are not directly connected to the hoarding problem they are reported at the end of the section.

Chapter 6 is devoted to review of the work closely related to the hoarding problem. The support for disconnected operations is neglected by e-learning society, but in the mobile computing in general it is an important question. Different approaches are presented which are developed for specific cases of disconnected mobile systems and are compared to the hoarding in the learning scenario we pose.

Chapter 7 gives a short overview of the thesis work and is dedicated to the conclusions and deductions made throughout.

Chapter 8 gives some ideas for the future work, based on the currently proposed hoarding approach and improvements on the developed Mobile ELDIT system.

Finally a complete bibliography is followed by some appendixes that comprise other interesting work conducted within the thesis. At the end a list of journal and conferences articles published during the thesis is given.

Chapter 2

2. Mobile Learning State of the Art

Computing technology has been applied to learning for decades, but it has really flourished with the advent of the Web. In recent years the quick growth of mobile technologies is promising a new revolution that might be comparable with the Web. The forecasts for 2004 [95] were that about 63 millions handhelds will be sold world wide, and that approximately 38% of them will be smart phones, integrating PDA functionality with features for communication. And the forecasts are already getting true since, according to DoCoMo [87], more than 37% of Japanese population owns Internet-capable phones. More and more mobile devices with improved capabilities are appearing on the market. In fact according to Canalys [99] in the beginning of 2006 "13 per cent of all mobile devices will be smart-phones", which will number 16.9 million. Again according to [99] "by 2008 more than 130 million smart-phones will be selling worldwide each year" and "Yankee Group predicts that there will be more than 300 million smart-phones in circulation by 2009". Though the numbers vary in different sources there is a clear tendency for fast growth in the number of mobile devices. Lots of mobile clients already support Java (J2ME) making it easier and less costly to develop portable applications.

Mobile learning (m-learning) is a field which combines mobile computing and e-learning. Will e-learning undergo a revolution as it happened with the Web? We do not know, but we must try to answer the question, by trying to imagine how mobile devices can enhance e-learning or modify it. Many people are working in this new field, and it is increasingly difficult to have an overview of what is going on, since most papers are dispersed in many conferences, and some reports are only available as grey literature. Here an overview of what is going on is presented. By

no means were we able to discover all the interesting papers that have been published in the field, but from the inevitably partial view we tried to let emerge the trends that characterize the field.

2.1. Defining M-Learning

There are number of different definitions of mobile learning. Often m-learning is described as e-learning through mobile computational devices. Alternative definitions emphasise on the mobility of the learner, rather than the device. Here we focus more on the first definition and while in general by mobile device we mean PDAs and digital cell phone, more generally we might think of any device that is small, autonomous and unobtrusive enough to accompany us in every moment in our every-day life, and that can be used for some form of learning. We shall begin by enumerating the different ways such a device can help us. In first place, they can allow us to *interact with people*, via voice and through the exchange of written messages, still and moving images. A second possibility is to consider them as tool for *accessing content*, which can be stored locally on the device or can be reached through interconnection. Under the same category we might include *accessing services* that can be seen as dynamically generated content. The functions that are offered by such devices are therefore not different from what can be done with other devices, in the same way as mobile telephony is not intrinsically different from residential telephony, but the change of boundary conditions induces a new use of the media. Also, the different interface that such instruments have (small screen, small or no keyboard) has an impact on what is reasonable, useful and even pleasant to do on such devices. For instance, reading a digitalized book on a Palm is today barely acceptable, and reading it on a cell phone is probably unacceptable for most people. Even browsing the Internet is an experience not comparable with doing it on a PC.

So while some research concentrates on how to *best perform the same action in a changed environment*, some other focuses on *what actions are best suited to new conditions*. On this

last aspect, the ability to contextualize, i.e. to take into account *where the user is* (in space and time) and *what the user is doing* in order to propose the best suited activity is a big challenge, that goes under many names (the most popular of which are *ambient intelligence, and ubiquitous, pervasive or sentient computing*).

Research on pedagogical use of the new media is a wide open field. On the more technological side, infrastructural research on mobile computing is of great help to m-learning, since many problems in m-learning are in common with *m-anything*.

We shall try to review these different aspects. The rest of this section will therefore follow the structure we outlined here. We will begin by covering infrastructural research, since that is a common denominator. We then will examine the problem of accessing content from the learning perspective, and we will move to facilitating interaction with other people.

2.2. M-Learning Research

2.2.1 Infrastructural Research

Access to the web through personal electronic devices, with their small screen size, has been an interesting problem for lots of researchers. Unfortunately, today most web pages are designed to be displayed on desktop computers with colour monitors having at least 800x600 resolution. This leads to at least 4-to-1 (often greater) ratio of designed vs. available screen area, making direct presentation of most pages on the small devices aesthetically unpleasant, un-navigable, and in the worst case, completely illegible. Work is being done in the area of device independent access to web content. In this context different approaches are proposed for describing device capabilities (HTTP Request Header, CC/PP, UAPROF, etc.). Also different architectural approaches are developed for using the information of devices' capabilities and adapting the content accordingly. The adaptation could be server-based (XML/XSLT, Cocoon, Axkit), proxy-based (AvantGo, Palm Web Clipping) and client-based (XHTML/CSS). A comprehensive survey of current technologies for device independ-

ence and device independence activities can be found at [12] and on www.w3.org (detailed reference [108]).

Adapting the content through transcoding servers is one of the often used techniques. The web content is retrieved from the Internet by the server and is converted into a form suitable for the device. Different transcoding techniques are used for simply translating from one presentation language to another (e.g. WAP-HTML-WAP), for reducing the content size [54], for satisfying bandwidth or screen capabilities of the devices [8][9], to adapt the structure of the content in more appropriate logical fragments [86][41][113] or to present the content in some symbolic way [35]. Some solutions also face the problems of connection speed and processing capabilities of the devices for delivering streaming media [91]. All these approaches though suppose online access to the content. Only some of the transcoding proxies (e.g. www.AvantGo.com) take care also of caching web pages for off-line usage.

Caching and synchronization are two of the main problems of mobile applications in any domain. Mobile devices are often disconnected because of the lack of access in certain places but also because of the high prices in most of the cases. Two different situations arise – when the device is disconnected on purpose, but the user wants to work and when the connection fails during his work online. Depending on the application and the data needed the requirements of the first situation can be met by using AvantGo or other client-side caching mechanisms (see e.g. [114]). Although thick-clients can be used to maintain the synchronization and the caching there is still the problem of the small amount of memory available on the mobile devices. The data should be carefully separated and only the necessary pieces should be uploaded.

Other approaches provide special services for mobile devices. The delivery approach can be different, such as the Satchel architecture [61][29], which provides a distance access through a special browser to documents and other resources needed during work. Mobile web services could be also used as Microsoft and

IBM released versions of Web Services Toolkits for mobile devices. This enables access to Web services on enterprise servers, but although there is a big potential in Mobile Web Services there are some disadvantages and problems that should be overcome. One of them is loss of network connectivity – the service is not available if there is no connection and the question of how a system should recover from a failed web service stays open. It is also not clear how the services are discovered in peer-to-peer networks and how to manage the resources of the devices. These issues are the objective of research like Microsoft Marlin project - (http://research.microsoft.com/research/sv/Marlin) - Mobile Access to Resources Living In .NET.

Context is observed in variety of fields in everyday and business life that profit from the usage of mobile devices. Solutions for various scenarios are proposed, like personal context storage system [81], support systems [17][77], and location-aware shopping assistant [10]. A survey of context-aware computing and applications can be found in [23] and in [55]. Nevertheless some authors, like [67] and [13], discuss that a special support is needed for the mobile learning domain in order to carry its specifics. Context information for m-learning and the ways it is supported is discussed in more details in Section 3.2, where we talk about the architecture to support m-learning.

Usability of different mobile devices through different activities is also an important issue in multiple domains. Work and experiments have been done for improving input usability of the small devices [68][69][85], towards improving readability [76], displaying multimedial data [105][18], etc.

Location discovery can be performed with various techniques. Some systems use the Global Positioning System GPS, but they work only outdoors. Some indoor-positioning systems offer context-aware services: the Active Badge System [110] and WIPS [112] (Wireless Indoor Positioning System) use infrared beacons. Active Bat [111] uses ultrasonics, the Cricket system [79] is based on a combination of ultrasonics and radio. SpotON [40] uses signal strength of radio signals. In some recent research

the discovery of the position is based on the wireless signal of Wi-Fi networks.

For mobile learning the infrastructural research described so far is just the technical base for reaching certain practical goals, for developing concrete systems and to explore the possibilities offered by technology for the learners and educators. In other words they are to be used further to allow either access to content and services, or communication and collaboration between participants. During the initial phase of the doctorate some work was done on utilizing location information for providing context dependent service to mobile learners. This work is presented as Appendix on page 177.

2.2.2 Accessing Content

Accessing content is one of the most important functionalities in e-learning and it takes a big part of the research efforts in m-learning too. Generally based on the infrastructural research mentioned above for transforming data into format suitable to mobile devices, some research specializes in adapting courses for mobile devices, and in building learning WAP portals. The most obvious use of mobile devices for educational purposes is in fact a direct application of the e-learning techniques on smaller devices instead on a desktop PC. For grown-up people studying is by default arranged on courses, lectures, classes, etc. A logical sequence is the development and experimentation on transforming traditional courses in a form appropriate for mobile devices.

The *M-Learning* project is one of the projects that have a special section dedicated on creation of a WAP portal for educational purposes. More concretely this is the part developed at Ultralab (i.e http://www.ultralab.ac.uk/projects/m-learning/). The technical aspects in the creation of a WAP portal for educational purposes do not differ from a common WAP portal. As the target users for this project are young people (age 16-24) with literacy problems, the group studies the problem of keeping the interest of the young adults to the useful learning materials, by exposing also

modish and exciting subjects. A special attention is paid on the pedagogical aspect of education.

The *M-Learning* project team is also producing offline m-learning materials for people with literacy and numeracy problems [20][102]. A great potential is encountered from the cognitive and pedagogical point of view. Learning modules are created by using standard tools (like Macromedia Flash, in its version for mobile devices). The preliminary conclusions are that new technologies have great impact on students' interest in the subject studied. In this case this was one of the main wanted repercussions.

The positive results of many more systems, developed to combine WAP courses and SMS notification systems, were published by different universities in the last couples of years. A few examples are *HyWeb* [45] at Griffith University Gold Coast, *mid-2000* [107] at Minnesota State University and the *NAIT* (http://www.nait.ab.ca/MobileLearning/) *m-learning* project in Canada.

An m-learning project that focuses on the testing of the use of WAP technology in higher education is the *UniWap* project [83][84][88]. The team tries to explore the process of creating an operating environment for studying and teaching through smart phones and WAP phones. The Virtual University needs to support the mobility of the participants of the learning process (the students and also the teachers). One phase of the project was to create some working prototypes (courses modules) and to investigate the problems and the value of such courses. The positive results they encountered (easy to develop, willingly accepted and widely used modules) encourage them to continue investigating the new coming technologies – digital imaging with mobile devices, 3G, etc.

"From E-learning to M-Learning" is a long-time project (see http://learning.ericsson.net/leonardo/thebook/book.html) that aims to create a learning environment for wireless technologies by developing course materials for range of mobile devices. A discussion about the characteristics of the devices that are proper

for learning is made when taking the decision about what devices to use in the project. An analogy and differentiation is made between e-learning, d-learning (distance learning) and m-learning and in this context they try to foresee the future of m-learning and the methods and technologies that should be used for successful m-learning.

In the attempt to find the best way to apply mobile devices in education people are experimenting with different fields: one of them is language learning. At Stanford Learning Lab [92] an exploration of m-learning has been done by developing prototypes that integrate practising new words, taking a quiz, accessing word and phrase translations, working with a live coach, and saving vocabulary to a notebook. They envisioned that a good approach would be to fill the gaps of time by short (from 30 seconds to 10 minutes) learning modules in order to use the highly fragmented attention of the user while on the move. The research indicates some very useful directions, like the length of the learning materials, the personalization of interaction and the frustration of the user and low perception of the learning materials because of the poor technological implementation (i.e. poor navigation through the materials; poor cellular connections, etc.).

One thing often discussed in e-learning field is adaptation of the learning content – both in the ways it is presented and its structure to the specific learner's needs. Logically the research on adaptation continues in the m-learning domain. As previously, one can discuss the adaptation of the content for the concrete user, but in m-learning the adaptation is needed also towards the device that is used and to the surrounded environment. It should be mentioned that the adaptation should be ensured on an architectural level, so apart of some references given here, more details in this direction will be given in section 3.2.4 (on page 60). In [34] a system is presented that utilizes a multi-dimensional framework to support adaptation. The adaptation both to the user and to the device is discussed in detail in [50] and shows that modelling of the user is a very important step and in most cases rules should be mapped to the full list (combinations) of parameters describing

the users' learning styles. A unified approach to educational content adaptation for mobile device is proposed in [103]. These and many other sources, like [51], [116], etc. also suggest that adaptation in mobile learning is very important and opens many technological and pedagogical issues.

For supporting adaptation additional information might be needed, specific for the mobile learning context. For this reason a possible need would be an analogue of e-learning metadata, as proposed in [13] for extension of the metadata standard for the needs of the mobile scenarios. It will comprise not only the data about the learning material itself, but also about the learner and his/her learning history and the setting where the learning process takes place.

As mentioned earlier an important factor in mobile environment is to embrace also the context. The *MobiLearn* project (www.mobilearn.org) is one of the biggest and most important European-led research project and is an example where also the context information is taken into consideration in the architecture phase. Participants in the project discuss the importance of location-dependent learning, like presenting learning content on the spot, i.e. information given to the students while visiting museum. As *MobiLearn* is a large International project it has broad band of goals, like creating a general framework for m-learning, creation of pedagogical paradigms, exploration of adaptation for mobile devices and realization of a new business model together with prototypes implementation, understanding in depth the process of learning in different contexts, etc. The target users are workers and citizens in their everyday learning activities, e.g. citizens visiting cultural city and its museums or family members using simple medical information on the spot.

2.2.3 Communicating and Interacting with People

Interaction can have little structure (messaging) or be highly structured, for reaching a goal as in collaborative and problem based learning. In both cases new technology has much to offer. In the case of highly structured interaction, pedagogical models

come into play in an important way. Activity theory, theories of adult informal learning, lifelong learning and etc. are at the basis of lots of experiments using mobile devices.

Let us start with the simplest interactions. Although simple learning-related applications may benefit from the messaging capabilities of mobile systems, only relatively few different educational bodies have made experiments in this area.

At Kingston University (UK) an experiment was undertaken to research the effectiveness of a two-way SMS campaign in the university environment [96][97]. The team has developed a system that sends SMS to students registered to the service. The content of messages is about their schedule, changes in it, examinations dates and places, student's marks, etc. After registering the students were automatically separated in 5 different groups. One group was receiving announcements via e-mail, other 3 groups via SMS (but different interaction was necessary in every group) and the last – via web. The conclusions of the experiment were that the students in certain scenarios where a certain type of response is required preferred SMS as a medium to e-mail or web-based announces. They feel the data is more personal and they like this. SMS could be efficiently used in education (m-learning) as a complementary media. As the technology improves (i.e. EMS and MMS, the potential for more user-friendly interfaces) the potential increases too.

At the University of Helsinki the *LIVE* (*Learning In Virtual Environment*) experiments made on SMS system and with WAP phones, were very positive [89]. The project went on by introducing digital imaging and sharing photos between the participants (teachers). The conclusions were that it is very possible that the introduction of MMS and the other 3G services in the large scene will lead to more and more possibilities for m-learning.

Another project [31] on evaluation of a Short Messaging System (SMS) to support undergraduate students was done at Sheffield Hallam University. The experiment was with 67 undergraduate psychology students. The implemented system was for managing learning activities (to guide, prompt and support the

students in their learning) rather than for learning. The findings were overwhelmingly positive, with students perceiving the system to be 'immediate, convenient and personal'.

Positive results were underlined in the outcomes from a survey in Norway - almost 100% of the students in that University have cell phones and an SMS system would be widely accepted [26]. Once again an SMS system was considered to be used to spread information about lectures and classes, corrections in the schedule and etc. In certain cases students find it more convenient than e-mail or WWW as the information reaches them in real time.

Let us now consider cases of more structured interaction.

One of the earliest initiatives in the m-learning domain is the one of University of Birmingham – the *HandLeR* project (http://www.eee.bham.ac.uk/handler/default.asp). The project tried to explore the lifelong learning. The stress is on communication and on human-centred systems design. The main concepts they investigate are concept mapping and knowledge sharing, lifelong learning, wearable learning technologies and conversation between mobile learners.

Similar in some concepts to *HandLeR* is the project undertaken at the Tampere University of Technology, Finland [48] where PDAs are used for improvement of the mathematical skills of children. The study-content is presented in the form of a game (again the idea of human-centred education is explored) where the pupils can communicate and help each others and the electronic device is used to measure the average students' knowledge level and to adopt the speed of presenting new material to the learners'.

To support "Problem-Based" Learning was the aim of *KNOWMOBILE* project in Norway [94] where PDAs and smartphones were used for experiment in medical education of students from the School of Medicine at University of Oslo. The students were put in different environments and were given different devices (some of the students were living together and had PDAs with the possibility of peer-to-peer connections to each other; in another group students were able to connect between each other

via the Internet but were working in separate locations, and so on). After few weeks of experiment the team found out that the students were using the devices mainly to read information from a digital medical handbook (not to retrieve it via Internet as it was expected) and as a communication device (to discuss problems with colleagues but mainly for sending SMS messages and to organize social events after hours). The research found that the reason for this was that whiles the medical students were eager to test the PDAs and investigate how they can be useful in learning they still had some technical difficulties. With proper guidelines and education the students might overcome these problems. They concluded that the PDAs should not be regarded as Personal Digital Assistants, but rather as gateways in complicated webs of interdependent technical and social networks.

Research on new forms/tools for collaboration has been going on in different institutions, schools and Universities. In different projects people are experimenting on collaborative conceptual mapping and notes-taking systems [49][71]. An example of such collaborative work is a project that took place at MIT [53]. The team used PDAs to simulate the real environment (in the form of map) and to use simulation for a game, played by kids. They use PDAs equipped with GPS extensions. The idea is that the virtual world simulated on the PDA (which has the same geographical characteristics as real world) is “polluted”. Kids have to take “virtual” probes from the water and/or air in the polluted area or surroundings, analyse the results, interview people and read information about similar situations and finally find out how to sublimate the environment. During the game they collaborate by doing different probes and analysis and giving the results (reports) to their classmates or leaving them (probes and reports) in a certain place in the area (map), where other kids can find and use them. The kids have to collaborate because they are forced by time limitations.

Advanced wireless technologies (IEEE 802.11, Bluetooth, and GPRS) are used in a project for development of ad-hoc classroom and *eSchoolbag* system at the Aletheia University in Tai-

wan [15]. The so called "Paperless education" is being observed together with the acceptance from the students (the term "paperless education" and research on the topic is made also in (http://www.paperlessclassroom.org/). The traditional classroom was replaced by the new developed electronic tools (electronic blackboard, rubber, colour chalk and so on). Pupils were strongly encouraged to communicate and to learn together (in groups).

Applications for recording the data and taking notes have been developed for Palms and the pedagogical effect of them has been analysed [3][93].

Again in Taiwan [65] students were equipped with network-connected PDAs and their achievements were shown on a whiteboard. The results from the pedagogical point of view were again very positive (as the students were very shy they preferred to keep quiet and the teacher could not find out the real level of their knowledge). Compared with traditional classrooms, virtual environment and technology motivate more participation and collaborative dynamics between instructor and learners.

2.3. Guidelines for m-learning applications

We have been trying to catalogue research on m-learning in three main areas: infrastructure, content and communication / collaboration. We shall here conclude first by providing some guidelines for m-learning applications, and then by summarizing the direction in which we believe valuable contributions are expected.

The nature of mobile devices, with their small screens and poor input capabilities leads to the assumption that they can not replace standard desktop computers or laptops. But the same properties can make them efficient in learning domain. We report here some guidelines that can be found in [95][28].

- Modules should be short, and last no more that 5-10 minutes. Users should be able to use their small fragments of waiting or idle time for learning, by reading small pieces of data, doing quizzes or using forums or chat.
- Simple, funny and added value functionality. The computational power and other properties of mobile devices make it

difficult in most cases to use complex and multimedial content, although devices of the same size are used for entertainment with great commercial success. It should be possible to use an m-learning system without reading a user manual, and the experience of studying with the help of such devices should be interesting and engaging.

- Area/Domain specific content, delivered just in time/place. The mobility should bring the ability to guideline and support students and teachers in new learning situations when and where it is necessary. The dependency of the content can be relative to location context (i.e. the system knows the location where the learner resides and adjusts to it), temporal context (i.e. the system is aware of time dependent data), behavioural context (i.e. the system monitors the activities performed by the learner and responds to them adjusting its behaviour) and interest specific context (i.e. the system modifies its behaviour according to the user's preferences).

It should be mentioned that as far as we are aware at the time when these guidelines were presented (in the beginning of 2003) no other work in this direction was available. More lately a profound work on gathering guidelines for m-learning was made in the context of *MobiLearn* project and presented in [106].

As far as future directions are concerned, we think the main research topics could be the following:

- Pedagogical research is immediate and topical. Different learning approaches involving mobile devices should be considered and observed, to find which ones are the most effective given the conditions in which m-learning happens.
- The lack of convenient input tools pushes the research in exploration of new forms of user interfaces – for example sound or mobile scanning tools as input/output.
- The small screens of the existing mobile devices give many research opportunities. Digital materials, used in e-learning should be at least partially reused, but a specific adaptation is required for them to serve m-learning needs.

The best way to do the adaptation would be, of course, automatic customization/conversion. In a general sense research in the area of device independent presentation of data serves also other domains, but an investigation is needed to find out which are the special requirements of m-learning.

- Related to e-learning are the services that students and teachers need, and that are typically provided by Learning Management Systems. Providing such services via mobile devices is an applied research direction.
- E-learning always depends on the connectivity of the end user. With the mobile devices there are periods of poor connectivity or no connectivity at all. M-learning could therefore be delivered in three different ways: "pure connection", "pure mobility" and mixture of the previous two. "Pure connection" is when the mobile device is always connected to Internet (through WAP, GPRS, UMTS, Bluetooth, etc.). "Pure mobility" is when no connection is available and so all the data the applications need should be uploaded on the device and used offline. The first option gives strong impact on context-dependent applications, while the second approach needs research on data management.
- Adaptation to the surrounding context in a mobile environment is also a very interesting and promising area.

Finally, we note that whenever a new technology comes, it takes a while until its real potential is deployed, because we continue thinking according to old paradigms. We probably have not yet found the new paradigm for fully deploying e-learning, and yet another variation comes. It is up to our ingenuity to free ourselves from the "old thinking" and unleash the power of our fantasy to allow a new revolution to happen.

Chapter 3

3. The Research Context

This section outlines our research context. The first sub-section presents a survey performed in a cooperation between the University of Trento, Italy and the University of Rouse, Bulgaria. The aim of the survey was to see the readiness of the university students for mobile learning. Afterwards we present the general mobile learning architecture with elaborate analysis of how it was designed and what each module is responsible for. The third section is dedicated to the Mobile ELDIT system, developed according to the general architecture mentioned, that demonstrates in practice the research issues triggered through the thesis. Explanation of why and how it was developed is given together with some technical details about its modules.

3.1. Survey on the readiness for mobile learning

To start planning the development of a mobile learning system we analysed the available literature to benefit from other people's experience. Looking at the wide variety of mobile learning projects, their aims, diversity of devices used and even the target audience we were wondering if the previously gathered knowledge applies in our scenario. In this context we tried to investigate the factors that might help in predicting the success of an m-learning application in a more concrete situation – the University environment. We performed a study on the readiness of the University students for using mobile technologies in their study process. The survey was done in May-June 2005 in parallel at the University of Trento, Italy and the University of Ruse, Bulgaria. An online questionnaire was developed and the students of different faculties were asked to fill it in. For the majority of the questions participants were asked to choose from predefined single or multichoice answers. However for some questions they had to write an

explanation of their opinion, argumentation for certain answers and also to describe their idea, view or imaginary picture in free-text. The questions were split into thematic groups, like "Availability of devices", "E-Learning Usage", "Opinion about prices", etc. Later on we performed grouping of the users according to their answers to specific questions and did the analysis and deductions. A complete report of the students' answers, full statistical data and comparative graphics can be found in a separate report [104], while here we give a summary and some of the most interesting and important results for this thesis.

3.1.1 General Information

About 600 Italian students participated from the University of Trento. They were mainly from the Science and Engineering disciplines (respectively 30.6% and 57.6%), but also from more humanistic faculties, like psychology, economics, languages and other (in total 11.4%). Considering gender 71.1% of the participants were males, which is due to the fact that big part of the participants (more than 50 %) was from the engineering disciplines, where in general the percentage of male students is noticeably greater than the one of females. The students were evenly distributed between the different years of their study (both bachelor and master) and mostly less than 25 years old (87.3%). About 95% of the Italian participants were of Italian nationality.

Bulgarian students were about 200 and were with more smooth distribution across University faculties. Nevertheless also here students from technical specialties were more then 60%. Also here the main age group was under 25 (78.3% of the participants) and the boys were more than the girls (61% vs. 39%). Different years of study were almost equally covered.

3.1.2 Availability of devices, their usage and attitude to prices

Devices: One of the main concerns when trying to introduce a new service or technology, in our case m-learning, is who will be able to use it. This is partially dependent on what devices will be used, how many users posses those types of devices, but also if

the users are prone to spend money for acquiring a device if a new service appears that needs one.

Our study shows that more than 95% of Italian students and almost 90% of Bulgarian ones posses a cell phone (see Figure 1). Personal computers are also often owned by participants of this study – 81.2% of Italian and 75.3% of Bulgarian students. In addition Italian students often have also laptops (55%), only some have PDAs (7%), videophones (7%) and Smart-phones (3.7%). These percentages are quite small for Bulgaria (less than 2%).

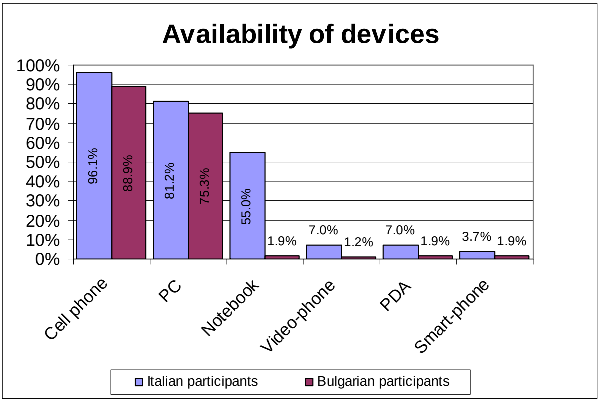


Figure 1: Availability of devices

The devices that are mainly involved in the research in m-learning are mobile phones and PDAs. So we asked the students about the reason for them not to have one. The answers differed in Italy and in Bulgaria. Considering PDAs for most of the Italians the main reason is that such device is not useful for them (59.4%), followed by the high price of the devices (41.6%), expensive wireless services (13.9%), devices' limited resources (11.1%), etc. For Bulgarian students the major concern is the high price, both for the devices and for the wireless services (more than 75% of all answers) and only after this comes the answer that the device is not useful for the respective student (12.2%) and the limited resources of the device (5%).

Prices: Considering participants' attitude to prices of the devices the general opinion is that while personal computers and cell phones have acceptable costs (for PCs more than 65% of all participants and for cell phones more than 54% of IT and 60% of BG students) the prices of laptops and PDAs are considered high (by more than 52%). Moreover lots of the students have no interest and thus no opinion about the prices of Smart phones (more than 60% of Italians and about 50% of Bulgarians) and PDAs (35-38%), while the "no opinion" percentage is rather small for other devices, as shown on Figure 2 below.

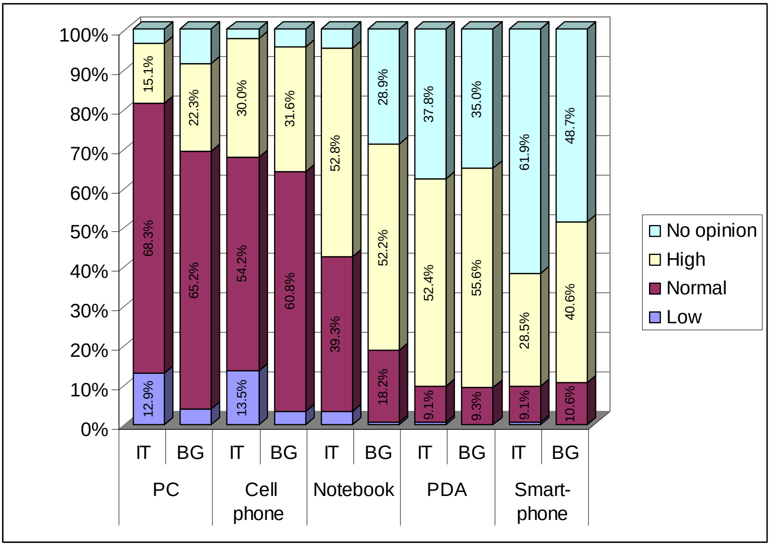


Figure 2: Opinion about devices prices

When talking about prices of services we can see on Figure 3 below that the usage of cell phone is still considered costly by 66.4% of Italian and 72% of Bulgarian students. Less then 2% of the participants consider these prices low. About 30% of Italians and 21% of Bulgarians think that the prices are normal.

The situation differs little when talking about prices for using the Internet (also shown on Figure 3 below). The opinion that the Internet usage has a normal price is considerably higher in

confrontation to cell-phone services – 38% in Italy and 49% in Bulgaria. However the opinion that the prices are high is still strong – about 50% of all participants.

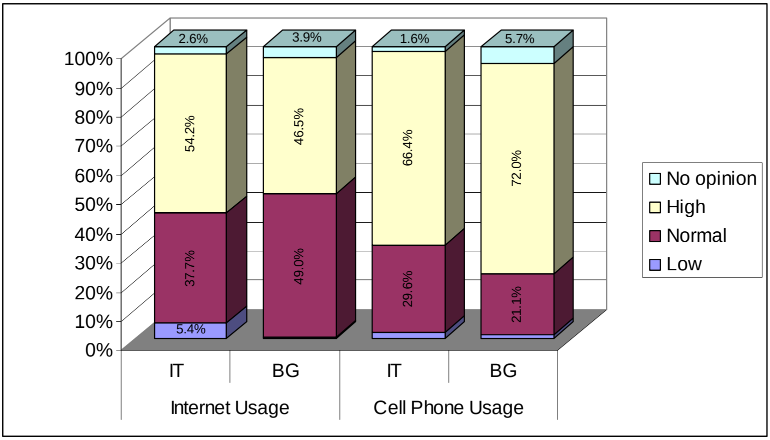


Figure 3: Opinion about services prices

Usage: We have tried to discover how our participants use the devices and services available to them to see if we can anticipate its influence on mobile learning. Focusing on the connection type that is used by the students at home we found out that for Italians a relatively large share falls to ADSL connection (53.6%), followed by modem connection (38.8%) and in total 93.8% of Italian participants use the Internet from home. About 90% use the Internet also from University or work. Quite a lot use access from public libraries (22%). On the other hand in Bulgaria 37.3% of the students do not have Internet access at home, ADSL is almost not utilized at all. The Internet is used also often from work or the University (72.7%), public libraries (17.4%) and in this case from Internet cafes (14.3%).

Students report that they use Internet in wide variety of ways – for searching for information (97%), for studying (82%), for entertainment (74%), for online shopping (30%) and other activities. Slightly more often it is used during work days and the major part of the Italian students do it for less then two hours a

day, while a big part of Bulgarian students report also usage of 3-7 hours a day. In both cases it was noticed that more boys use Internet for longer periods.

A relatively small number of participants report to access the Internet from their cell-phones (7.2% in IT and 14.3% in BG). More than the half of the all students gave as reasons for having a cell phone that it gives them the freedom to communicate and that it makes their life easier. For only 2% the cell-phone is fashion. Almost everybody is using the phone for conversations (about 98%) and to send and receive SMS (93%). Nevertheless they report a small number of SMSs sent and received daily. For Italy less then 5 SMS a day are sent by 67% of the students and received by 65%. For Bulgaria these percentages are even bigger.

3.1.3 Ways of usage and attitude to e-learning platforms

Mobile learning is often considered the next step of e-learning provoked by the new mobile technologies. It was noticed that there are some differences in the ways students use e-learning and one of the presumptions that we wanted to test is if those differences extend to their attitude to m-learning. In this section we only report the similarities and differences we have discovered and in a later section we discuss how we think the students' experience with e-learning influences their feelings about m-learning.

We have found that the ways of using e-learning differ slightly in the answers of Italian and Bulgarian students. The reasons might be partly because of the different offering of their own university's e-learning platforms. For example the percentage of students that do not use e-learning is about 36% for the University of Trento and almost 10% less (≈27%) for University of Rousse. Differences in the ways e-learning is used were found also according to the studied subjects in both universities – at the University of Trento non-technical specialties utilize more the university platform then technical ones, which is on the contrary in Bulgaria. This led us to believe that most probably the reason is in the number and variety of learning materials published on every

university platform for every single course or specialty. Generally when the university platform offers good set of materials students prefer to use this unique source, otherwise they look for other e-learning platforms or even just sources on the Internet.

Nevertheless there are gender differences that appear in the same manner in both groups (Bulgarian and Italian students): The percentage of the girls who use only their own university's e-learning platform is about 10% higher than the boys. The percentage of girls who use different platforms is almost two times lower than the boys. The percentage of girls who do not use any platform is higher compared to the percentage of boys.

More generally the most often given reasons for using e-learning are convenience, increased availability of the learning materials, higher speed of access to the materials, the possibility to search through the lectures and other digital sources, access to large volume of useful learning information and etc. Some people mention that the quality of the lecture is increased by the existence of e-learning resources connected to the studied subject and that this gives ability for a personal improvement and qualification. Other often given reasons in favour of the more modern approaches and extensions of the traditional university education are: the cost of the books - sometimes printouts are even omitted by using lecturers' slides or other digital materials available via the e-learning platforms; the less need to be physically presented at the university, thus sometimes skipping costly and time-expensive journeys; the ease to compensate the loss of a missed or skipped lecture, etc.

On the other hand a reason frequently given against e-learning is the lack of personal contact between teachers and students. Students often prefer the traditional educational approaches – blackboard and chalk, reading books in the library and everyday contacts at the faculty (for University of Trento these are about 80% of the negative and neutral opinions). It should be mentioned that even some of those students that have positive attitude to e-learning as a useful medium to fast and time-independent access to learning materials mention that it is a 'cold' environment and

that there is a lack of personal contact. For many students e-learning is “not necessary” or even quite useless at this stage because, unfortunately, material is not provided for a given specialty/subject or e-learning is not supported by enough courses they participate or because it is not well supported (materials are not updated often enough). An interesting opinion of a student is that “e-learning is yet not enough mature/well developed to be useful”.

Also technological obstacles, like slow connection via modem, are mentioned more that once as a problem which makes e-learning not so comfortable and pleasant to use. The connection speed proves to be a major consideration as about 40% of the Italian and 17% of Bulgarian students use modem connection at home.

Some participants mention that the computer distracts during the study, other say that e-learning is “too complicated”, or that a long usage of the computer is tiring, especially for the eyes, but also the cost of the computer itself (considering that for using e-learning you are obliged to have a PC or a laptop) and the cost for the Internet connection appear to be a problem.

When asked about the connection between e-learning and the quality of University instruction most of the students think there is such and it is a positive one. About 75% of the Italian and 85% of Bulgarian students share the opinion that e-learning increases the quality of the university studies. This is valid even for more than 50% of those that have never used e-learning.

We have also asked the students if they would like to have access via Internet to video recorded lectures of the courses they follow. A bit less then 85% of all participants were positive and more than 60% think that this possibility will not decrease the face-to-face attendance of the lectures. For this scenario we did not find meaningful gender, age, specialty or other influencing factors.

3.1.4 What about m-learning?

First of all we should mention that very little of the students knew what mobile learning is and have ever used it – only 4.6% of the Italian students and 2.5% of the Bulgarian participants. All of them use also e-learning and were mainly boys (74% of the Italian and all Bulgarian participants). It should be underlined that an m-learning platform is not offered by any of the two universities for the studied subjects. In this section we give a complete analysis of the students' answers on three main questions, namely

1) would they like to use m-learning and why;
2) will in their opinion m-learning increase the quality of education and why;
3) what services should mobile learning provide.

Q: Would you like to use m-learning? Why?

As most of the students were not familiar with mobile learning or had never even heard of it a short description/definition was given. Afterwards they were asked if they would like to use m-learning and why. In free text they described their feelings and expectations rather than real impressions or knowledge.

Almost 60% of Italians said they would like to try m-learning. The most often given reasons for positive attitude to m-learning is the students' curiosity and willingness to use new technologies and innovations - about 35 % out of all positive answers. Answers like "I love technology" or "I like anything that has to do with technology" or just "Why not?" were not rare. Other answers include expectations of much increased accessibility of learning materials, real-time information, better time scheduling, time-saving, allowing more freedom and flexibility.

Some students describe their view of m-learning as a way to substitute traditional learning, e.g. "I will not travel 30 km. to participate to the lectures" or "I will be able to watch the lectures while lying on the grass near the lake or travelling in the train".

In some cases students do not think they belong to the potential users of m-learning but still have a positive attitude (for example “It might be useful for those who can not participate in lectures nor use e-learning”); others say they have not the possibility to use m-learning as they don’t have the needed devices.

On the other hand quite often the explanation of a negative attitude is “I’m not interested” or “I don’t see it useful”. There are students who prefer more traditional approaches – books, paper notes taken by hand and etc. These are generally the same people that do not use e-learning for the same reason. Also here, as often mentioned for e-learning, some students feel that there might be the lack of interaction between teacher and students – more than 25 % of the negative answers. There is also the opinion that this new technological approach will bring more distraction than concentration, generally will increase the study time (in the sense of students being much more unproductive), and thus is out of consideration.

Other repeatedly given argument against m-learning is that PDAs and cell phones are not able to give more to a learning system than what already exists in e-learning, e.g. “Internet is good enough!”; “Better e-learning”; “I believe it will not be that handy as e-learning” and “I don’t find it useful to do with the cell phone or a PDA in much less comfortable manner what I can do with a laptop”. Further, students mention as obstacles the high cost of the devices and the connection, the small devices are not enough technologically advanced to be useful for education (mentioned the small screens, small space, etc.), not comfortable for long periods of usage, might lead to health problems e.g. “May cause eye troubles”. Other interesting answers: “I hate the computer!”; “I would use it only if it does not substitute the professor”; “I will feel myself followed”.

From Bulgarian side there is more potential interest – more than 80% of the participants would like to try m-learning. The most frequently mentioned reasons are that there are no limits in terms of time and place; it will give more easy and convenient access to learning materials; this is a modern educational technol-

ogy; it will be attractive and useful. Students often mentioned more than one reason to use mobile learning. On the other hand the most frequently mentioned reason for not using m-Learning is the lack of financial resources - high prices of mobile communications and devices; limited or no access to mobile networks; the students' mobile devices don't support new mobile technologies as GPRS, EDGE, etc. Some students do not feel any need to use it or find m-Learning is unsuitable format to present information. Many feel they are unfamiliar with this technology (mainly students from faculties different from engineering) and others think that the quality of education will decrease. Only few answers are totally negative - "It is unnecessary", “I don't find any advantages and applications of m-Learning" and “I don't like this education!".

Q: In your opinion will m-learning increase the quality of instruction? Why?

Though lots of students are curious and would like to try m-learning some (57% of Italian and 27% of Bulgarian students) have major doubts that the quality of instruction might increase by using small mobile devices in university education. Moreover it seems students do not connect the quality of instruction with the addition of supporting services via mobile devices. One of the reasons often given at the University of Trento for m-learning not augmenting the quality of instruction, although it might be interesting and useful, is that during lectures mobile devices generally distract people instead of helping them concentrate.

The students that think m-learning will increase the quality of the University education very often give as motivation one of the following expectations: the availability of real-time information; availability and accessibility to more information; increased freedom in sense of location-independence; higher integration of the study process into everyday life; time-saving; more interesting form of the study process, thus higher motivation to do it.

Some students see the problem that m-learning will be used by a few people and thus even if the presumed mobile learning

system is very nice and useful the University education in general will not become better for the major part of the students.

Some of the answers put into mind the doubt that there is no full understanding and sometimes there is even misunderstanding of m-learning and its potential. For example in one student's comment it became clear that he excludes the possibility that an m-learning platform is web-based, or another student that wrongly believes it is impossible to visualize lecturers' slides on mobile devices (probably considering only cell phones), etc. In the questionnaire we have only a 2-line loose definition of what mobile learning is. It should be also mentioned that in some cases the students wrongly connected the idea of mobile learning with the one of video registered lectures accessed via mobile devices, which was by oversight influenced by a previously given questions about video lectures in an e-learning system accessed via Internet or on CD. Probably this led also to lots of the negative reactions to m-learning, as people see the devices not strong and comfortable enough for looking video on them. In our opinion a different (probably more positive) outcome might be expected if the students are given more concrete scenarios and situations embracing mobile devices in different learning processes.

It was noticed that quite a big part of those who answered that they would not like to use m-learning still think that its existence will increase the quality of instruction (about 10%). Most of them are students that think that attendance at the lecture and immediate contact with the colleagues and professors is very important. Nevertheless they consider m-learning might be very useful if for some reason other students can not be present at the lectures.

About 25% of those who declare they possess a PDA type device say they would not like to use any m-learning system. Reasons include: lack of humanity and personality, too much distraction, while learning demands good concentration. A few people declare that they would tolerate m-learning only in the cases that it is additional support or in cases they are hindered from participating in the face-to-face lectures.

We must also mention some original students' answers: "The quality of education doesn't increase in dependence of the place from where you learn, it increases in dependence of your wish to learn", “The modern student is delocalized and the educational institutions must encourage his/her global thinking and performance and not to restrict him/her in terms of time and space", “The students can participate in interesting lectures which are not in the frame of their educational profile".

Q: Which services must mobile learning provide? Describe how you imagine a mobile learning system.

For this question the students were first given a list of possible services and had to check which seemed useful for them. Afterwards they were supposed to describe what they imagine will be offered by a mobile learning system and what are the services they consider valuable. A large number of students’ answers discuss as possible services all or part of those mentioned in the list given by us. Others suppose m-learning should provide the same functionalities as e-learning whenever possible.

Summing up all students responses students expect that most helpful and used will be the services in the following order:

1. To access supporting educational information (e.g. schedulers, exams results) via WWW (79.4%)
2. To communicate with teachers (65%)
3. To access educational content online (54.4%)
4. To communicate with other students (53.7%)
5. To receive supporting educational information via SMS/MMS on demand/request (50.5%)
6. To fill-in tests and questionnaires for exams (39%)
7. To collaborate with other students (38.4%)
8. To fill-in tests and questionnaires for self assessment (31.8%)
9. To access educational content off-line (29%)
10. To receive supporting educational information via SMS/MMS always (23.7%)

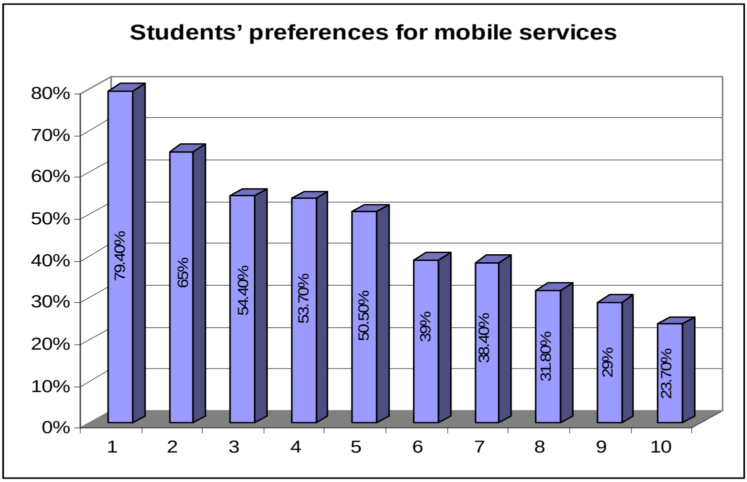


Figure 4: Students' preferences for mobile services

As one can see more positive weight is given to supportive services. A few people mention that they just can not imagine the didactic material viewable with mobile phone, but are very optimistic for the rest. Some mention the fact that they expect that these services will be free of charge for the regular students and teachers of the University, based on authentication. A frequent vision is of a system utilizing the university wireless network, sometimes supposing a high-bandwidth connection.

An interesting supposition very often found in the answers is that mobile learning should be the medium to facilitate the communication and collaboration between student-student and student-teacher, probably because of the students perceiving the cell phone mainly as a device for conversations. Another repeatedly given hint is that a nice university supporting m-learning system should be strongly integrated with the university e-learning and available there services. As imagined by students an m-learning system is often quite complicated and should offer all possible features, including rich multimedia and video. Only in some rare cases the students presume 'simple' software with

‘clear’ functionalities, though often assumption is the simple and intuitive interface, fast and comfortable system.

Other interesting views:

“It should reproduce the university environment. It should provide all services provided in the Secretariat (like certificate requests and etc.). It should facilitate the communication between students and teachers and push the students to interact between themselves (via forums, instant messaging, e-mail, etc.). Different lectures should be available on the net, in video/slides and text or at least providing full references.”

“First of all it should be fast and constant (the service should be always available)”

“I think that the technology already exists (PDAs, cell phones, notebooks). They only have to be made useful and be used. The big problem is often the cost”

“… It will be very nice to be able to integrate the lecture notes with the video registered lecture…”

To sum up the main services which m-learning must provide: to support rich and actual educational information; it must be an information system to support traditional learning by providing the following: a timetable, abstracts of lecture themes, test and exam results, messages, to carry out tests and questionnaires, etc.; to ensure fast and convenient access to learning materials conformable to the resources of mobile devices; regularly to send information via SMS/MMS about news or changes; to ensure abilities for the students do download and read off-line files on mobile devices; to present briefly and clear the information on subjects; to ensure more close and fast connection between students and teachers; to ensure active connections with other e-learning systems.

Finally more than 66% of the students see the future of m-learning as a support system for the traditional forms of instruction. The percentage of the students which consider m-learning can work as an autonomous system is almost equal to the percentage of those that think m-learning has no perspective (a bit less then 10%). About 15% do not have opinion about its future.

3.1.5 Deductions

Differences according to e-learning usage: We have studied if the ways students use e-learning affects their answers about the m-learning and we noticed that it does.

On the first place there is a difference in the attitude to having a mobile device other than the cell phone. A noticeable trend in the answers of Italian students is that the percentage of “A PDA device is not useful for me” answers is related to the e-learning usage – 50% for those who do not use e-learning, 40% to those who use only the University’s platform and about 30% for those using multiple e-learning systems. This happens at the expense of the answers giving as reason the price and the limitations of the devices, which are respectively – (35%|8.2%); (40.5%|12%); (45.5%|16%).

When asked about the expected relation between m-learning and the quality of university education most negative (as might be expected) are the students that do not use e-learning – more than 60% negative. From the people that use only University’s platform 56% are negative and from those that use more than one – about 50%. None of those who ever used m-learning consider it to be without a future.

It can be noted the trend of 5% difference in the number of people that have tried an m-learning solution – from the people that do not use e-learning the percentage is close to zero; from people that use only their own university’s platform it is about 5% and between those who use more platform it becomes about 10%. The difference in the attitude to try m-learning is even bigger – about 10%. Positive are about 50% of the first group, slightly more than 60% of the second and almost 70% in the third group from the Italian students. Respectively the numbers for Bulgarian students are about 70%, 80% and 90%.

In brief the students’ attitude to mobile learning seems to be closely related with the students’ ways of usage of e-learning: the more they use e-learning more positive they are to the next e-learning step. In our opinion the roots of this are deeper - in the students’ feelings towards technological approaches, in their per-

sonal study habits and strategies. Nevertheless when talking about the services that should be provided by a provisioned m-learning system no insignificant preferences can be found for grouping based on this criterion.

Gender difference: Some gender differences were noticed throughout the questionnaire. The differences might be qualified mainly as a slightly more positive attitude and interest of male participants to technology in general, thus to new things and experimentations. It was noticed a 10% gender difference in the type of available Internet connection Italian students have at home (Modem F-46.6% vs. M-35.9%; ADSL F-45.9% vs. M-56.5%). Our interpretation is that often males tend to acquire the newest and fastest technological solution. More female participants have the feeling that prices of PC and Notebooks are high, but on the other hand they consider more often the prices of cell phones and services as normal or low. Male participants are more aware of the prices of PDAs and Smart-phones. In our opinion these findings might be an important factor when choosing what an m-learning system should provide. In the cases when a new device should be acquired we should expect more males to be interested at initial stages, while if the medium of providing the future m-learning services is a well-known one (e.g. cell phone and SMS) females are more eager to explore it, thinking less about the price.

Males are also more convinced that m-learning would enhance the quality of instruction (both for Italy and Bulgaria with about 10% difference comparing to female answers). This might be also explained with girls feeling more comfortable with more traditional tools and media.

Differences according to the nationality: There are noticeable differences between Italian and Bulgarian students' opinions only for a few parameters. In some cases the differences in the answers might be due to the much lower general income of Bulgarian students. Though we did not directly ask the students about their incomes some deductions can be made based on their answers. For example there are almost no Bulgarians that consider any of the

prices low. This percentage is quite often small also for Italians, but the difference is sometimes up to 10%, e.g. prices of PCs and cell phones. The balance changes only when talking about the price of Internet connection where 10% more Bulgarians consider it normal. This is probably due to the fact that in Bulgaria there are wired network providers and cable-TV operators that often provide also quite cheap Internet. Though these seem national differences in our opinion the origins should be searched elsewhere. Of highest importance for the students is the cost, both for acquiring the devices needed to use a certain system and the price to be paid to access its services. One can see this also in the students' opinion about prices – for any kind of device 10% more Bulgarians consider its cost higher compared to Italians.

However about 10% more Italian students do not use any e-learning solution and the general attitude of Bulgarian students both to e-learning and m-learning is definitively more positive. About 10% more Bulgarians think e-learning enhances the quality of their education and more than 20% more Bulgarians are eager to use m-learning. The difference rises to 30% when the question is if mobile learning will increase the quality of instruction. Our suggestion about this difference is that in the last year or so at the University of Rousse different surveys and questionnaires are given to students to find out the ways to improve the quality of instruction and often students see the changes based on their suggestions. In those surveys mobile learning is often mentioned and students are probably more informed and more optimistic about its success.

Differences according to the studied subjects: We did not find any specific differences depending on the studied subjects. The small exception is the fact that the percentage of the students of University of Trento from non-technical specialties that use any e-learning platform is bigger compared to engineering specialties (unexpectedly) – more than 80% vs. about 63%. On the other hand "non technical" specialties generally use only the University's platforms, while about half of the engineers use also other platforms. As the situation at the University of Rousse differs, i.e.

engineering specialties use e-learning much more often and a big number of non-technical specialties students use more than one platform we think that the reason should be searched in the quantity and the quality of the material offered by specific courses and programs.

Differences according to the owned devices (PDAs): As mentioned earlier we were expecting that the attitude to m-learning will be strongly related with the devices owned by the provisioned users. We had looked at the answers of people who posses a PDA device and it can be noticed that more than 20% of them (for Italy) have tried m-learning. Though this statistic is based on very few participants it is obvious that the percentage is much higher than the one of people without PDAs that have used m-learning. From Bulgarian side no student that owns a PDA have ever used m-learning. The attitude to all of them though is noticeably more positive. Nevertheless their expectations to what functionality to be provided are very similar to all other students.

We shall mention that we were not able to study well if differences can be found according to the age of the students, as our participants were much concentrated in one age-group, namely less then 25 years old.

3.1.6 Related Work

Almost the same survey was done at the University of Rousse two years ago [33]. Interesting to mention are the changes in the answers of the students with the passing of time. On first place the percentages of devices owned by students has not changed notably. Also students' perception about the prices of Internet usage stayed almost the same. Considering prices of cell phone usage the opinion that they are "normal" decreased while the number of answers "high" increased. Also noticeable is the opinion that PCs and cell-phones prices tilts more to "normal" than to "high". Though these are important to notice more interesting are the changes about the real usage of e-learning and the attitude to m-

learning. For both the percentages increased significantly – for the e-learning usage by 15% and for willingness to use m-learning by about 7%. Our explanation for the first change is that at the time the initial survey was done (end of 2003) the University e-learning platform was not loaded with learning material. Only some courses were offering material online, thus the system was not used a lot. With more courses having published materials and updates the usage increased appreciably. One can notice also the difference in the places from which students access Internet. There was increased access from home probably because, as mentioned before, in the last few years cable-TV operators started to widely provide comparatively cheap Internet. Also the drastically increased access from the university (increase of about 40%) is due to the increased number of computer halls for free access for enrolled students. This is on behalf of usage from Internet cafes. Another assisting factor is the augmented speed of Internet connection in University's classrooms. With the advances and with much more publicity of mobile technologies it seems natural that also the interest for trying their application in education will increase.

Very similar to our study is one on the actual usage of mobile technology by students, done at the Norwegian University of Science and Technology, Trondheim [25]. The study shows that mobile phones are widely used in Scandinavian countries, while PDA devices are still limited. We should mention that in contrast of our survey, the one presented here is a small-scale, only 25 participants who participate in the same course. The study was oriented to improving the communication and collaboration between students and teachers through mobile technologies, which is specifically needed for the concrete course. In fact students' ranking of the services they expect to be provided by a provisioned mobile learning system does show that they need more collaboration. Nevertheless their study shows very similar result to ours about the mobile phones usage, i.e. almost everybody has a mobile phone and the main functionalities used by the students are phone calls and SMS. WAP, calendars, synchronization with

PC, e-mail, GPRS and etc. are rarely utilized. It is noticeable that also here the authors suppose that often the students do not use the full potential of their devices (even on cell phones) because of the high costs of the services. One should pay attention that the cost factor did not change over a few years.

Another very similar study was done at University of Oulu (Finland) with the aim to explore university students' conceptions of their needs for mobile tools and what kind of features they would appreciate [66]. Their survey also reveals that 100% of the participants posses a mobile phone, but use it mainly for calls and SMS. 83,5% have never used a handheld device and quite a lot do not have laptops (41%). The already existing wireless network is also very rarely used, only by 17.4% of the participants. "The results of the study states that 86% of the subjects want to read their emails via mobile device, 57% want to use library services via mobile devices and 30.5% of the subjects are interested in using the learning environment in a mobile device". Students' attitude is that "mobile learning environment could be used mainly for information delivery and discussion". Some also mention that in their opinion mobile devices are not adequate for visualization of content.

In [42] a survey wais done on the students' attitude to use W-CDMA phones in classrooms. Their conclusions are that students are happy to do it, but different models of the devices give different possibilities/functionalities for different students, which (the lack of homogeneousness) might be a problem. The use of new media increases pupils' interest to certain activities; still the phones are mainly used for communication and collaboration via voice calls and text/picture messages.

A study conducted at University of Dublin (Ireland) [74] led to a strong expectation of the authors that the future of learning is bound to mobile and wireless. They testify fast growth in computational devices and Internet use for educational purposes in their institution. At the same time they note that funding for providing enough devices to students might be a problem. In their

opinion students will be reluctant to pay for such devices for themselves.

When talking about general statistics and predictions about the usage of mobile devices lots of studies have been done for different countries – USA, Japan, Republic of Korea, Morocco, Norway and etc. [43]. All of them show that cell phones are spreading very fast and are owned and used by nearly 100% of the young people. They are used at various locations and SMS is quite popular. On the other hand PDAs and smart-phones are considered business-oriented devices and are rarely owned by students, see [5], thus are probably not the best choice in the context we consider here. Other sources [72] and [19] show that students are the top consumers of mobile content, thus the best audience for the coming mobile applications and this fact should be used by the Universities.

At the same time practical experiences reported in [101] show that very accurate planning should be done, for both devices to be used and software applications that will be needed and utilized by the students, for achieving success in an m-learning system. The students' interest might be quite higher if they are supposed to use their own devices. Instead if the device is borrowed they are not that eager to invest their time in learning how to use the new media. Anyway in this experiment the students were using PDA devices mainly for organizing their time and rarely for more closely related to the study process tools.

Studies on the success of real mobile learning applications in practice show a big success. For example [100] shows that more than 70% of teachers that used Palms in K-12 classes feel their positive contribution and only 5% fully disagree with the statement that handhelds will help improving the quality of classroom learning activities. Other sources, like [5] and many others described in the 'State of the art' section of this thesis also show the good success of once implemented for a specific audience solutions.

3.1.7 Conclusions

Here we presented the outcomes of a parallel survey made throughout Italian and Bulgarian university students together with a study of similar surveys done by other bodies. The goal was to discover important parameters that might influence the success of a provisioned mobile learning system. These parameters should be closely observed and cautiously considered in design phase.

Our findings show that students' attitude is strongly related to the ways and frequencies of usage of e-learning. Students that are comfortable and use willingly e-learning are much more positive to m-learning.

A very important factor for a successful m-learning solution will be the choice of devices to be used. Generally students' opinion is that (except cell phones) small mobile devices and their exploitation are very expensive. Most of them will not be eager to buy device, unless they see very strong positive ways of its usage. Mobile phones that have much increased recently resources seem to be the best choice in University environment, though the wide variety of models might be a problem. Nevertheless the price of the service is always considered by the students.

The general attitude to technology is also a strong factor. Males tend to be more interested to experimenting and trying new things, while females often prefer traditional approaches. However once accustomed to a certain media type girls tend to use it more often. This should lead to the expectation that in a newly developed m-learning system the initial users will be more male.

We could not find any differences in the students' attitude to m-learning connected to studied subjects and specialties, nor to nationality. Nevertheless all students expect a strong support of wide variety of services, well developed and often updated m-learning platforms with strong integration to e-learning solutions.

In our opinion the results presented here show clearly that the future of mobile learning is bright, though lots of effort should be done to satisfy students' high expectations, to ensure a high rate of its utilization.

3.2. General mobile learning architecture

As mentioned before e-learning is growing very fast and many Universities and companies are already supporting in some way an e-learning solution. Online courses, web-based education, computer supported training and even virtual university are already wide used terms. The rapid development of wireless infrastructure and the advent of mobile devices in people's everyday life push the research in uniting those two domains, which results in the emerging of mobile learning. Considering the functionalities of e-learning system we analyse the possibilities to extend it to provide services for mobile devices. This includes distributing didactic material, user identification and authorization, gathering of data relative to the user-system interaction, provisioning of mobile services etc. We find suitable an architecture that provides interoperability between the e-Learning Management System (eLMS) and the mobile Learning Management System (mLMS) whenever possible. This will allow to deliver content and other services from the eLMS to the small devices by giving the possibility to reuse what is already available. At the same time the mLMS should take account of the unique properties of the mobile learners and the mobile technology.

In this section we give a description of what e-learning is and the services generally offered by e-learning platforms. We also give a description of functionalities of m-learning and the problems in the transition from e- to m-learning, which lead to the proposed general mobile learning architecture. Certainly various scenarios exist in which the learning material is different from what is discussed here or a different pedagogy approach is applied. However specific scenarios and related to them services, like for example mobile communication or informal teamwork, should be additional and will not be discussed here. In some of those cases the proposed architecture will not apply, while in others those specific services should take advantage of the modules described here.

At the end of this section also the related work is presented.

3.2.1 E-learning

E-learning has two main facets: the first is relative to using technology to support distance learning, the second is concerned to enhance the learning experience with the help of information technology. In the first case the learners and the instructors can be physically separated (they may never or rarely meet for face-to-face lectures, discussions, etc.) and thus the whole learning process is technology-mediated. In the second scenario the traditional learning approaches can be supported with complementary services, like online delivery of the learning materials, support for collaborative work, virtual communities etc. In many cases both aspects are simultaneously present. The goals of e-learning systems and the functionalities they offer can differ: the needs and goals of know-how transfer in an industrial company are quite different from the educational needs of a university. The functionalities can be broadly grouped in four categories: access to resources (data), specific e-learning services, common services and presentation. We intend to first list the main services and then discuss how these services must be modified with the introduction of small ubiquitous devices.

- Resources
- Support of learning objects (LO) – any digital material, link to other resources, active element (like simulations etc.). Breaking the educational content into small pieces allows modularity and reusability of the content. These chunks of digital resources can be rearranged in modules, like lectures and courses. To facilitate this process they are usually described by additional metadata (as prescribed by the IEEE Learning Object Metadata (LOM) standard, for reference see http://ieeeltsc.org/).
- Support for Learning Metadata – repositories for metadata can help to catalogue learning objects, and facilitate search and reuse.
- Quizzes and questions – lecturers can create a pool of questions and answers to be used both for automatic formal exami-

nation (summative assessment) or self-assessment of the students.

- E-learning specific services
- Content management services – most e-learning system has the notion of Course and Lecture. A course can be composed by collection of resources: syllabus, one or many lectures, a structure for describing lecture sequence, forum, board, etc. A lecture is usually composed by many resources: presentation section, exercise section, additional material section. All these components should be organized and accessed through a proper engine. There could be searchable directories of courses, programs, etc.
- Assessment - one of the main advantages of computer-supported learning is the automation of some important processes. Self-assessment is one example. The pool of questions/answers and a suitable engine allow automatic generation of different versions of tests and quizzes and also automatic checking of the results, evaluation of performance and comparison with others' results.
- Knowledge management (KM) – today most e-learning systems do not really support knowledge management services. KM in general aims at extraction, summarization and organization of explicit or tacit knowledge from data sources (e.g. Web, e-mails, chats, etc.). Application of KM to e-learning can be of vital importance in companies, while in university context (where most of the knowledge to be acquired by the students is explicit and formalized) it can be a useful but less relevant addition.
- Tools to support learners and tutors in managing their learning resources – some systems allow different users to have their own workspace and to upload personal resources (links, documents, notes, etc.), or to markup learning material.

- Common services
- Support of different actors (students, teachers, tutors, administrator and guests), and integration with the company's (univer-

sity's) information systems – different users typically have different levels of permissions. Unregistered users (guests) can have some (typically very limited) level of access to the platform.

- Collaboration tools: synchronous (chat rooms, shared applications, whiteboards, web-cast, audio- or video-conference, role games, simulations) and asynchronous (FAQ, forums, wikis, blogs, message/news boards, e-mail, mailing lists) – usually a few different services are offered for communication between users of the system (learners, lecturers, tutors, mentors). Some of these tools are mainly meant to support cooperative work, while others aim at sharing and accessing important or topical information.

3.2.2 M-Learning

According to the definition for m-learning we adopted and described in section 2.1, mobile learning can be viewed as any form of teaching or studying that happens when the user is interacting through a mobile device. It might include various scenarios and here we try to transfer the services provided by an e-learning platform (enumerated previously) into the mobile context. We can easily see that there are services that need to be adapted to fulfil the limitations of certain devices, there are other services that are infeasible to transfer, but also new services appear, provoked by the mobility.

The connectivity is one of the main differences if we compare a mobile device with the PC (the usual medium for delivering e-learning). Nowadays mobile devices might be connected to 'The Net' via lots of technologies – WAP, GPRS, UMTS, Bluetooth, WiFi, etc. Although it is predictable that in the future 'always on' will be wide spread, currently it is not the case. Mobile devices often have periods of disconnection, either intentionally (when the connection is too expensive) or not (when no infrastructure is provided).

Devices' hardware and software characteristics have a big impact on what content is possible and meaningful to be delivered. Usually the web content is designed for desktop PCs, thus unpleasant and even rarely useful from a small-screened device. Nowadays mobile phones became more powerful with amazing speed (both from hardware and software point of view) however their screens will remain comparatively small. Often also the navigation is difficult. Equipped with a small phone-style keyboard or a touch-screen (for the PDAs) users might lose more time in searching where on the page is the information they need than in reading it. We can think about alternative ways of navigation, for example voice commands. The memory available on a mobile device is also relatively small. It is possible to use extension packs on some devices like PDAs, which reduces some of the restrictions, but, also due to their additional cost, we can not presume their availability.

Location is a new thing to be considered. Although up to now we have been talking only about limitations confronting m-learning and e-learning there are also advantages. The small size of the device and the wireless connections make them available anytime and anywhere. The mobility opens variety of new scenarios. Services involving location-discovery are for example a student/teacher receiving directions on how to get to a certain room or alerts for seminars/lectures that can be triggered while taking into consideration the current place and the time to get to the needed classroom, location-aware printing of the learning content, etc.

3.2.3 The Architecture

We presente the functionalities offered generally by Learning Information Systems (LIS). The services approach (exposing web service interface to access these functionalities) allows flexibility, interoperability and possibility for extension. In this section we present an architecture that will provide access to learning materials and other services to users equipped with mobile devices. Our goal is to have an architecture which is:

a) General – to be able to provide all possible services offered to the e-learning users from the corresponding eLMS, but also to support services that are new in the mobile context.
b) Generic – to support different mobile devices (digital pones, smart phones, PDAs, tablet PCs and etc.) with different characteristics and be easily extensible for the new generation devices.

To achieve this goal we believe that the mobile system should sit on top of the traditional e-learning system and to provision adaptation of the existing e-services, like user identification, authorization, distribution of didactic material gathering of data related to user-system interaction and etc. In addition it should take care of mobile specific services.

On one side we have the mobile device, which will request access to the mobile system from a web browser, WAP browser or a specific application.

On the other hand we have the eLMS which exposes an interface to the services it provides. We note that only some of the possible services are shown on Figure 5. In the business logic layer these services might not be so clearly separated.

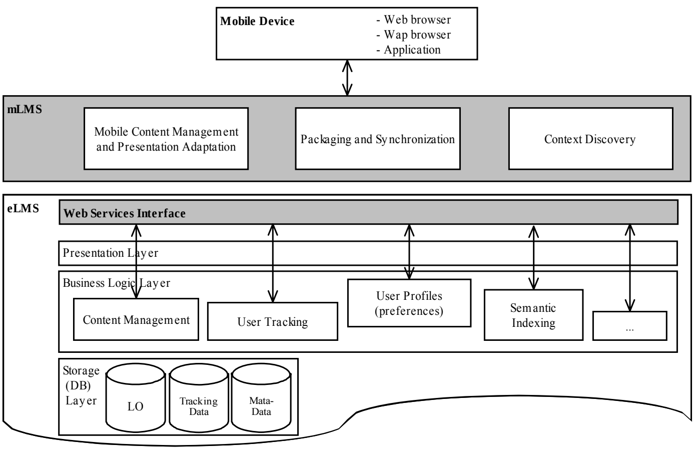


Figure 5: General M-Learning Architecture

We identify three main modules in an m-learning system, which stands between the mobile device and the e-learning system. They are the following:

- Discovery of context
- Content management and specific adaptations
- Support for disconnected operation

For helping the support of the services during offline periods and also gathering parts of the context information in some cases a small module will be necessary also on the mobile device.

Let's see the interaction between different modules by giving a simple example. We can imagine a scenario in which a user requests an interaction with the mobile learning system from her PDA. The system shows to the user a list of services which it can provide and the user selects to request more data about a seminar. The system provides to the user the information about the subject, speaker and location of the seminar, and if the user is interested also creates a reminder, which is triggered by the system depending on what time the user needs to get to the seminar room. Later the system gives to the user directions on how to get to the seminar room and during the seminar lets the user watch the slideshow of the presentation also on the PDA display. The user might take notes and attach them to the presentation slides. When the presentation finishes the user might go home and print his notes from his home PC. On the next day at the Faculty a friend asks about the seminar and the students decides to share with the other one his notes, by printing them on the nearest printer. The system gives to the user directions on where the nearest printer is located.

Let us now connect the scenario described above with the functionalities as they are executed by the different modules of the architecture presented on Figure 5. First the user request is captured and in order to proceed the system need to know who the user is and what is the device used. This is done automatically by the "Context Discovery" module, which (based on the first request or additional interaction) already holds the information about the user id and the capabilities and limitations of the device (both software and hardware). Based on this data the system can

check the user role (student, teacher, guest, etc.) and access rights in the eLMS and decide what services can be offered in this moment and propose the proper list to the user. After the next interaction with the user the m-learning system requests information about the seminar from the eLMS and triggers the “Mobile Content Management and Presentation Adaptation” module. Knowing the capabilities of the device (from the “Context Discovery” module) the data is redesigned and returned to the user. Afterwards the user requests the reminder to be set up for her. The system needs additional context information, namely the user location, in order to calculate the needed time to get to the seminar room. Once again the “Context Discovery” module is triggered to track the user current position which is changing constantly as the user moves and is checked regularly. Meanwhile, as the system ‘knows’ that the network is not accessible in the seminar room, it triggers the “Packaging and Synchronization” module. The eLMS might contain a large amount of materials concerning the seminar – the presentation itself, including explanations from the lecturer; related links; additional papers and examples; etc. As the system already knows the limitations of the device the “Packaging” module selects (with certain confidence) what part will be more useful and important during the seminar (for example only the presentation). In order to fit the device memory the system also ‘asks’ the “Presentation Adaptation” module to resize the images used. Before the presentation the chosen part of the material is seamlessly uploaded to the user’s PDA and is accessible when needed. When the seminar finishes and the user gets to a zone with a local network connection his notes are uploaded to the server by the “Packaging and Synchronization” module together with some tracking information. The tracking data will be used in the future for user modelling and decisions what materials are needed during offline periods to this and other users. On the other hand the notes are made available for further access online. Printing at home is done easily by accessing the University’s e-learning platform. On the next day when the student wants to print the notes at the Faculty building the “Context Discovery” is once again trig-

gered and the student's location is discovered. The system proposes the closest printer, where the student is allowed to print (based on his access rights) and is given instructions on how to get there from his current position.

Context Discovery

This module adds an abstraction that can hide the details about the different physical methods of context discovery. By context, as shown on Figure 6, we mean identity, spatial information (i.e. physical location), temporal information, environmental information (e.g. noise level), availability of resources (i.e. battery, display, network, and bandwidth), etc.

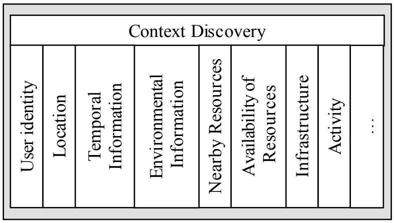


Figure 6: Context Discovery module

For example for finding location different positioning systems can be used – in one case the user will be outside and can use a GPS system and in another will be inside the building and will use the local network signal for that. A possible solution is the introduction of a 'conversion' server, which translates data from the format used by the device (GPS, WLAN, etc.) into format proper for the service that requests the context information. It is not necessary that the system detects all possible context data at the first user request for service. Some context data might be detected and provided when needed (on demand).

Mobile Content Management and Presentation Adaptation

Currently the main service provided by e-learning systems is the presentation of content. The presentation of learning materials is

an important issue and should be carefully designed. If, for example, the content will be accessed through a nowadays standard web-browser on the PDA then it should not contain incompatible elements, like scripts. Adapting e-learning material for a mobile scenario might imply something more than a simple reshaping of material or translating from one presentation language into another. It should be more precise and could involve different presentation logic than in e-learning - “Mobile Content Management”. The presentation adaptation can include adaptation of the structure, adaptation of the media format, quality or even type, etc. This module should be also used to adapt the presentation for auxiliary services, not only presentation of content.

Packaging and Synchronization

For allowing offline usage we need a mechanism for selecting what is needed by the user and also for taking care of content’s coherence and synchronization with the system. During the offline usage it is better to continue the tracking of the user activities and feedback the statistics to the LMS. This module should be able to predict which ‘learning path’ the user is most likely to follow and assign weights to the learning objects depending on how important they are for the next user session. The objects with higher weights should be uploaded to the device first; afterwards the materials with smaller weights should be uploaded until the device’s available cache is filled. The module should be able to analyse how successfully the previous uploads were done and improve further prediction.

3.2.4 Related Work

A work closely related to ours on defining architecture for mobile learning system, is on defining the requirements for a mobile e-learning platform, presented in [59]. The authors discuss the possible m-learning scenarios in respect of e-learning platforms and the functionalities an m-learning platform is best suitable for. Also the characteristics of the mobile devices are discussed to-

gether with predictions of their impact on foreseeable learning scenarios. What differs drastically in this work from our point of view is that the mobile platform functionalities are a direct mapping of the functionalities of an e-learning platform and only those that are impossible to deliver are excluded. In our opinion is important to foresee the support also of new services that are proper only in the mobile case, like location-dependent services.

In [67] context awareness architecture for mobile learning is presented. Similar to our "Context Discovery" module their "Context Engine" is responsible for gathering the context data. A very good description of context is given in a hierarchical structure with the notion of context states and sub-states, dynamics and historic dependencies of processes. The main difference from our "Context Discovery" is that authors suppose that all the context information is collected on the mobile device (including data obtained from sensors). Though we basically agree that very often the mobile device is active participant in the process of context discovery in our vision some context data can be extracted directly from the infrastructure (i.e. location) and will not always require adding extra load on the device (see Appendix B). Also, in our opinion, to have easily extensible system we should support the presumption that the context data might be needed in different formats by diverse applications and services. Such option would be possible to implement inside our more abstract framework by including a way to 'translate' the information properly. Still the work presented in this paper proves the viability also of our ideas. The authors also see the web services as most appropriate way for integrating their context-aware (sub)system with a mobile learning system.

In [90] architecture for m-learning based on web services is discussed. The analyses show that this technology is appropriate for supporting mobile equipped users in learning scenarios. The authors find one of the biggest challenges in the ability of such system to convert in satisfactory time the data (LO) from one format into another. They find the solution in preliminary (before request) creation of different versions. A major problem that we

find in this work is that the only way the system would support the offline usage of material is by manual users' request of pre-prepared modules ("students could easily access and download the entire course content anytime anywhere on their mobile device"). The authors also suppose that in all cases the entire course will fit into device memory, which is in contrast with our assumptions.

More recently, another web-service based architecture was discussed in [98]. A very positive attitude to m-learning can be felt from the paper, with authors believing that wireless m-learning compared to nowadays e-learning will provide much more multimedia oriented materials (More Voice, Graphics and Animation based instructions), richer collaboration and instant communication. The paper shows how the web-services model maps to m-learning. Authors emphasize on the necessity that the architecture is an open, standards-based model. Apart some differences in the concrete technological solution also here the system differs from our proposed model mainly due to the absence of the offline support module and the supposition of always available wireless connection, though they mention as future work the possibility to download entire course content on demand.

In [22] an architecture for ubiquitous learning (u-learning) is discussed, which should incorporate e-learning and m-learning. Basically the proposed architecture does not differ from our approach. The author cites our proposal with the only negative comment that no concrete implementation is provided, while their proposal starts from an established e-learning environment which they extend to include m-support. However we do not agree with the author's opinion that offline periods should not be supported. He assumes that in reasonably short period of time students will be able to afford GPRS or other connection whenever needed, which will satisfy all requirements of the u-system.

Within MobiLearn project, partially described in section 2.2, the OMAF framework was developed [21]. This work was published about the same time as ours. The framework, which is also abstract, provides a different view to a module base m-

learning, without specifying functionalities to be provided or the ways to do it. The main idea is to define a layered model and specifications for interfaces between the layers, so that to provide interoperability for already available and new services.

Another mobile learning prototype, based on detailed mobile learning architecture is described in [34]. Authors aim at the support of adaptation for mobile users. As the adaptation dimensions are content, user model, device, connectivity and coordination it turns to be quite general. In fact, from the point of view of functionalities it allows, is very similar to our proposal. The main difference is the absence of support for offline work. The shortage is known to the authors and is mentioned as crucial future work. The work was also published nearly at the same time as our work.

A lot of work has been done in the area of content adaptation for mobile devices and of device independent representation of web content. Different approaches are proposed for describing device capabilities; different architectural approaches are developed for using this information for adapting the content accordingly. A comprehensive review of the current device-independence technologies and activities could be found in [108]-a and [12]. Transcoding servers or proxies are often used for adaptation of content (see e.g. [62]), which is retrieved by the server together with the client preferences and constraints. Negotiation is done between the client and the server about the needed adaptations. Finally the converted content is delivered. Different transcoding techniques can be used for translating from one presentation language to another (e.g. WAP-HTML-WAP), for reducing the contents size, for satisfying bandwidth or screen capabilities, for adapting the structure of the content, etc. What is missing here is that generally only online access to the content is considered. Only some of the transcoding proxies take care for caching web pages for offline usage (e.g. AvantGo). Another point to consider is that in the learning scenario the content that is to be delivered could be sometimes quite large. We think that delivering content for offline usage is an important issue as still mobile devices are often disconnected because of the lack of access in cer-

tain places but also because of the high prices in most of the cases, thus our intention is to support both online and offline access to data.

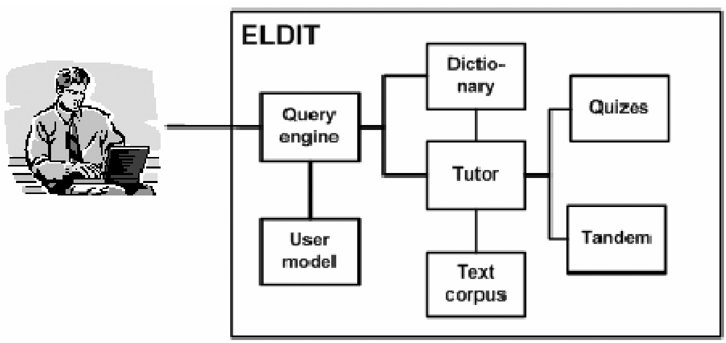
The off-line access to data is treated in the offline browsing of web content. The typical pre-fetching solutions offered by off-line browser utilities cannot be cast to mobile domain without taking into account the (severe) memory limitations of such devices.

3.3. Mobile ELDIT - A real-world system

For experimenting and doing tests in the field of m-learning and more concretely for studying the hoarding problem we have developed a real mobile learning system, called Mobile ELDIT. It is based on a system, called ELDIT [46], whose aim is to support language learning. Our system became also a proof that the general architecture described earlier is a viable model as Mobile ELDIT was developed according to the principles described there. Next we give more details on why we chose to develop mobile version exactly of ELDIT, what part of the online system were developed for mobile and why, together with more particularities and facts on both systems.

3.3.1 What? /Description of ELDIT/

ELDIT is an innovative electronic language learning system especially designed for the needs of the population of the bilingual region South Tyrol in Italy (http://www.eurca.edu/ELDIT). The system can be used by anybody interested to study the Italian or German languages, though its mobile version is mainly helpful for preparation for the exams in bilingualism in the mentioned area. This exam must be passed by everybody who wants to work in public administration.



** Source [46]*

Figure 7: Core modules of the ELDIT vocabulary acquisition system

The original ELDIT consists of different modules, including query engine and an intelligent tutor (see Figure 7) and has two main data streams – words corpus (learner's dictionary) and texts corpus with comprehension questions. The text corpus (about 800 texts, split into thematic groups and two difficulty levels, both for Italian and German languages) has been collected by the "Goethe Institut Milano" [1]. For ELDIT an XML version of the texts has been created. For major details about ELDIT see [46].

ELDIT is designed according to the principle of separation between data and their presentation. The data are XML formatted (see [108]-c) and the learning content is very low-granulated. The text corpus is the main part that is later adapted to be used via mobile devices. Every text is made of about 150 words and additional comprehension questions that the user should answer, as required for the bilingualism exam, in the other language. Words (currently nouns, verbs and adjectives) are connected to their entry in the dictionary. On the other hand each word entry contains explanations, translations and examples on different senses. It also provides additional information, like idiomatic expressions, derivations from the word, etc. The online system contains more than 600MB of raw data. Moreover such data are continuously growing as the ELDIT system evolves and the data are being enriched over time.

3.3.2 Why? /Motivations for the Mobile ELDIT/

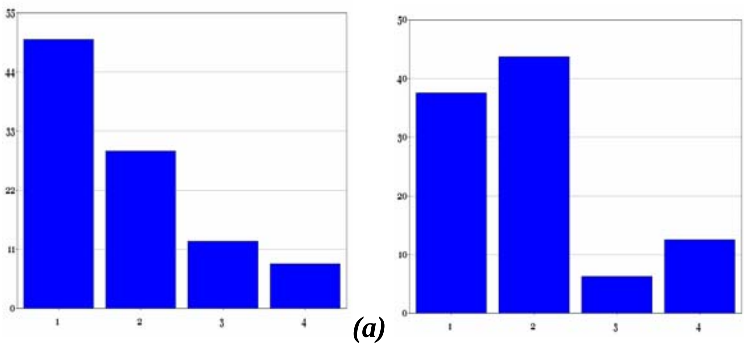
First of all the field that we have selected for our experimentations in mobile learning is the one of language learning, as language learning fits well in the boundaries that we placed, after analysing the work done in the mobile learning domain (see 2.3).

Our starting point is the ELDIT system (details in the section 3.3.1), developed at EURAC (European Academy Bozen/Bolzano). Our contact with EURAC and its geographic nearness with the University of Trento allowed close collaboration and simplified cooperation during the design of the mobile system, its development and also during tracking data collection in the experimental phase and analysis of results.

As mentioned earlier the online ELDIT contains a large quantity of learning material, which is an order of magnitude larger than the typically available PDA memory. Therefore it is obvious that the mobile version will strongly need a hoarding subsystem, thus ELDIT gave us a good opportunity for our final research goal – attacking the hoarding problem. However we still had to limit the Mobile ELDIT to only fraction of the ELDIT system as some of the functionalities of ELDIT were out of the scope of our current work, mainly due to time and resource limits. For example ELDIT allows the user to perform a free search for any arbitrary word in the dictionary which is unpredictable and would force uploading on the device the entire dictionary.

An online questionnaire has been made available in the Web-based ELDIT version and some of its outcomes were very useful for deciding what part of ELDIT to develop for mobile devices in the sense of their usefulness for the users and interest for mobile learning experimentations. About 90 persons have completed it up to October 2004. Some of the outcomes were valuable for the development of the mobile version and will therefore be listed here.

In Figure 8 one can see that users that had used ELDIT during their preparation for the bilingualism exams (that are more than 50% of all users) find the system very or quite useful.



(a) *(b)*

Figure 8: Do you find ELDIT useful for preparing the bilingual exam (a) Level AB and (b) Level C?
[1 – Very useful; 2 – quite useful; 3 – not very useful; 4 – useless]

This positive attitude made us believe that a mobile version of this system would be used and will be useful for the users preparing for the exam of bilingualism. Figure 9 shows that the main consideration in understanding an unknown word falls almost equally on definitions, examples and translations. In the mobile ELDIT they are presented on the first screen for word entry (see on page 74 Figure 17c). The rest of the information is presented to the user only if specifically requested.

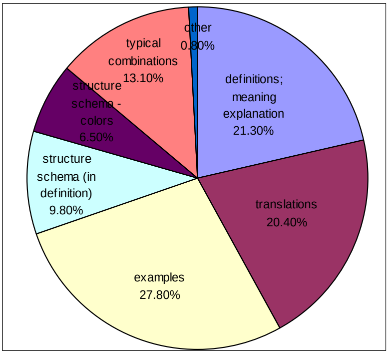


Figure 9: What is considered mainly for understanding words meaning?

Figure 10 and Figure 11 show the declared by the users usage time of ELDIT. Our goal was later to compare the usage of the online desktop and the mobile offline systems, having in mind that the mobile ELDIT complements the main system.

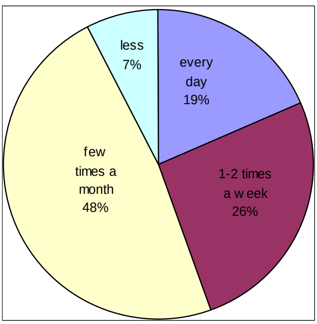


Figure 10: How often do you use ELDIT?

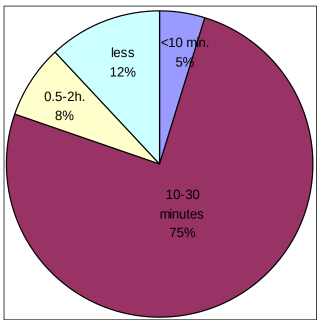


Figure 11: For how long do you use ELDIT?

Our preliminary conclusions were that language learning is a good choice as a field of the use of mobile devices. The ELDIT system, and especially its text corpus, is especially suitable for experiments on our hoarding problem. As people have different learning styles our expectation was that some should use the system to study in small gaps of waiting time, while others will prefer using the PDA just as an electronic dictionary available anytime. How these habits and stiles should influence the hoarding for a mobile learning system will be discussed further.

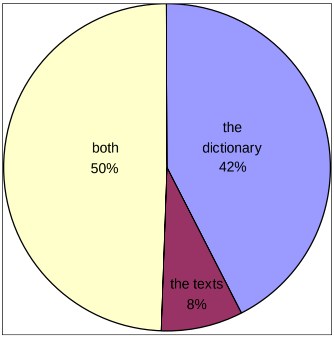


Figure 12: Do you use the texts or the dictionary of ELDIT?

On the other hand on Figure 12 one can see that ELDIT texts are used by more than 50% of the system users, which gave us the certitude that though the mobile ELDIT will contain only part of the original system it will be useful for the users.

3.3.3 How? /Details on Mobile ELDIT development/

In the developing the mobile version of ELDIT we followed the guidelines we extracted from the literature (see Section 2.3) for small and simple modules and also applied the principles described previously in the section 3.2 – "General mobile learning architecture", i.e. the separate/modular support for the three functionalities that are important for a mobile learning system: "Context Discovery", "Specific Adaptation" and "Packaging and Synchronization". We wanted to keep the user experiences during the use of the mobile version as close as possible to the online ver-

sion, so we used a web browser on the mobile device as interface to the Mobile ELDIT. Web-browsing is already very familiar to almost every user, therefore it is not necessary to learn yet another user interface. This makes the system very easy for the user to get used to and after few clicks the user feels already familiar with it.

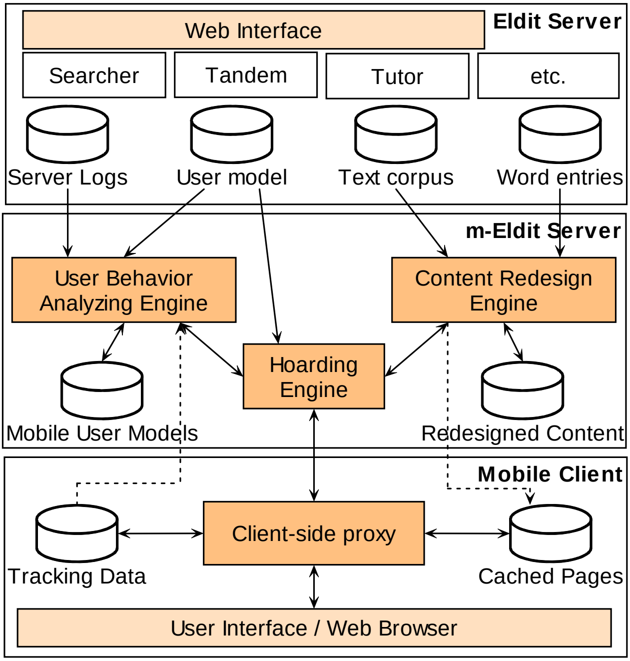


Figure 13: Architecture of Mobile ELDIT

Mobile ELDIT consists of two main parts: (1) server side, which we call the m-ELDIT server and (2) client-side, a proxy that serves to respond to browser requests during disconnected periods by providing the pages that are already in the cache and collecting the tracking information into log files (see Figure 13). Basically the log file is a list of user's requests for learning materials together with time information. These log files are the main source of information for analysing the user behaviour for the hoarding purposes. The server has the important functionality of adapting the content to the PDA by rendering it into proper format for the

device screen and displaying limitations (content redesign), for analysing the collected information about the user (user modeling) and for predicting the learners' future needs in order to prepare the material that will be used during offline periods (hoarding and pre-fetching). Also on connection the cache is filled-in with the predicted by the hoarding-subsystem set of learning objects (Note that throughout the manuscript we use the term learning object (LO) for referring learning units and more concrete separate HTML pages in the mobile ELDIT system. Nevertheless it might be any digital chunk of learning content that is in some way connected to the other chunks).

For the needs regarding content adaptation of the Mobile ELDIT system the only context information that has to be discovered is the device hardware and software limitations. Knowing the screen size, the browser type and the device's browser support for scripts and frames allows the "Content Redesign Engine" module to create the proper 'look' for the Mobile ELDIT pages. As a first step we chose the easiest way to discover the context – through the device browser's HTTP request that is captured on the server site.

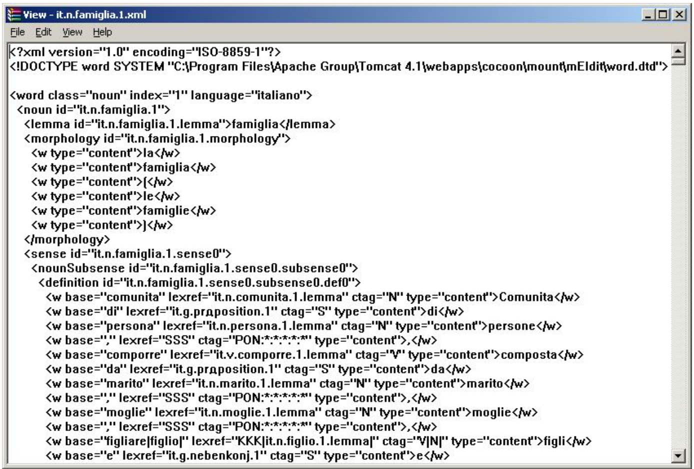
```
GET http://science.unitn.it/mEldit/text.056 HTTP/1.1
Accept: application/vnd.wap.xhtml+xml, application/xhtml+xml;
        profile="http://www.wapforum.org/xhtml",
        text/vnd.wap.wml, image/vnd.wap.wbmp, */*
UA-OS: Windows CE (POCKET PC) - Version 3.0
UA-color: color16
UA-pixels: 240x320
UA-CPU: ARM SA1110
UA-Voice: FALSE
UA-Language: JavaScript
Accept-Encoding: gzip, deflate
User-Agent: Mozilla/2.0 (compatible; MSIE 3.02; Windows CE;
        PPC; 240x320)
Host: science.unitn.it
Proxy-Connection: Keep-Alive
```

Figure 14: HTTP request from a mobile device (iPAQ Pocket PC)

The HTTP request (see the figure above) contains what we need, i.e. what kind of device is used (e.g. Windows CE device), what kind of screen it has (e.g. 240x320), the colour resolution (color16), the browser available (Mozilla/2.0), etc. In a more advanced version of Mobile ELDIT it will be possible to use other context discovery methods. There are quite a lot of technological solutions nowadays (for example the device independence initiative: www.w3.org/2001/di/). In another scenario the user might receive context-dependant (e.g. location-dependant) language learning material, like for example the system presented in [47]. For such scenarios additional equipment and other methods would be necessary, but it is out of the scope of this work.

As said before, in order to keep the Mobile ELDIT users' experiences close to the experiences with the online ELDIT system we chose to use a browser as an interface to the learning material. Most of the browsers on the mobile devices nowadays still do not support frames and have only limited support for script languages. This leads to the need of specific adaptation of the content. The adaptation is also needed because commonly web pages are designed for screen size at least 800x600, hence they are hard to be read and/or navigated from devices with smaller screens. ELDIT does not make an exception. Different adaptation techniques can be used to tackle this problem [12]. The adaptation can be done at server-side, it can be done in a proxy between the server and the client, or it can be done on the client side. Every one of these solutions has its pros and cons.

As mentioned earlier the data of the ELDIT system consists of XML files (example shown on Figure 15), both for the texts and for the word entries. For displaying the data on a desktop PC or a laptop dynamic HTML pages are produced on the server site. This is done on the fly on every user request in order to facilitate adaptation to the user. Another reason for generating the pages on the fly is that the data is often updated and new data is added continuously by the linguists. These pages contain frames and JavaScripts for easy navigation and the word entries are highly interlinked.

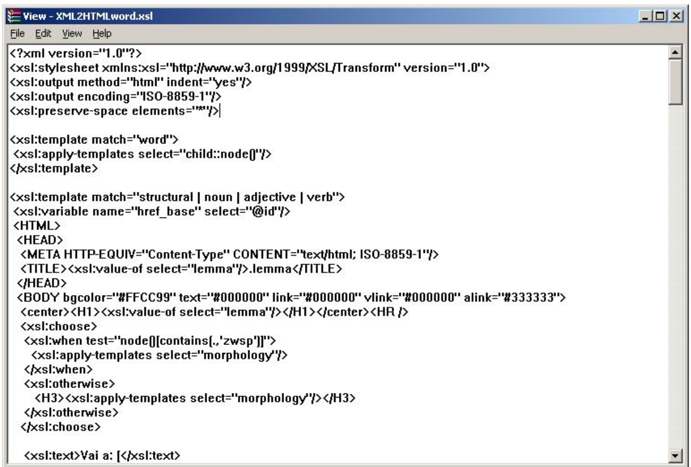



```
<?xml version="1.0" encoding="ISO-8859-1"?>
<!DOCTYPE word SYSTEM "C:\Program Files\Apache Group\Tomcat 4.1\webapps\cocoon\mount\mEldit\word.dtd">

<word class="noun" index="1" language="italiano">
 <noun id="it.n.famiglia.1">
  <lemma id="it.n.famiglia.1.lemma">famiglia</lemma>
  <morphology id="it.n.famiglia.1.morphology">
   <w type="content">la</w>
   <w type="content">famiglia</w>
   <w type="content">(</w>
   <w type="content">le</w>
   <w type="content">famiglie</w>
   <w type="content">)</w>
  </morphology>
  <sense id="it.n.famiglia.1.sense0">
   <nounSubsense id="it.n.famiglia.1.sense0.subsense0">
    <definition id="it.n.famiglia.1.sense0.subsense0.def0">
     <w base="comunita" lexref="it.n.comunita.1.lemma" ctag="N" type="content">Comunita</w>
     <w base="di" lexref="it.g.prдposition.1" ctag="S" type="content">di</w>
     <w base="persona" lexref="it.n.persona.1.lemma" ctag="N" type="content">persone</w>
     <w base="," lexref="SSS" ctag="PON:*:*:*:*:*" type="content">,</w>
     <w base="comporre" lexref="it.v.comporre.1.lemma" ctag="V" type="content">composta</w>
     <w base="da" lexref="it.g.prдposition.1" ctag="S" type="content">da</w>
     <w base="marito" lexref="it.n.marito.1.lemma" ctag="N" type="content">marito</w>
     <w base="," lexref="SSS" ctag="PON:*:*:*:*:*" type="content">,</w>
     <w base="moglie" lexref="it.n.moglie.1.lemma" ctag="N" type="content">moglie</w>
     <w base="," lexref="SSS" ctag="PON:*:*:*:*:*" type="content">,</w>
     <w base="figliare|figlio|" lexref="KKK|it.n.figlio.1.lemma|" ctag="V|N|" type="content">figli</w>
     <w base="e" lexref="it.g.nebenkonj.1" ctag="S" type="content">e</w>
```

Figure 15: Low-granulated raw data XML file

For Mobile ELDIT we have decided to use server-side adaptation, namely XSLT transformations (Figure 16) of the XML data (Figure 15) on a Cocoon server (corresponding to the ‘Presentation Adaptation’ module on Figure 5 in Section 3.1.5).




```
<?xml version="1.0"?>
<xsl:stylesheet xmlns:xsl="http://www.w3.org/1999/XSL/Transform" version="1.0">
<xsl:output method="html" indent="yes"/>
<xsl:output encoding="ISO-8859-1"/>
<xsl:preserve-space elements="*"/>

<xsl:template match="word">
 <xsl:apply-templates select="child::node()"/>
</xsl:template>

<xsl:template match="structural | noun | adjective | verb">
 <xsl:variable name="href_base" select="@id"/>
 <HTML>
 <HEAD>
  <META HTTP-EQUIV="Content-Type" CONTENT="text/html; ISO-8859-1"/>
  <TITLE><xsl:value-of select="lemma"/>.lemma</TITLE>
 </HEAD>
 <BODY bgcolor="#FFCC99" text="#000000" link="#000000" vlink="#000000" alink="#333333">
  <center><H1><xsl:value-of select="lemma"/></H1></center><HR />
  <xsl:choose>
   <xsl:when test="node()[contains(.,'zwsp')]">
    <xsl:apply-templates select="morphology"/>
   </xsl:when>
   <xsl:otherwise>
     <H3><xsl:apply-templates select="morphology"/></H3>
   </xsl:otherwise>
  </xsl:choose>

   <xsl:text>Vai a: [</xsl:text>
```

Figure 16: XSLT for word entries

Our decision was motivated by two facts: (1) on one hand our data was already in XML format (as shown on Figure 15), which allows an easy creation of the adaptation rules by using XSLT (example shown on Figure 16) (2) the adaptation on the server side is a much better solution in the mobile context, as the adaptation process consumes quite a lot of computational power and does not fit well on a mobile device, as the devices are limited in CPU speed, operational memory and battery.

Figure 17a shows a screenshot of a word entry of the ELDIT system, displayed in a desktop PC browser. One can see that it is made out of three frames. Meaning descriptive information about the selected word is shown in the left-hand frame and additional information in the right-hand frame. The frame on top is dedicated to the searching functionalities of the system.

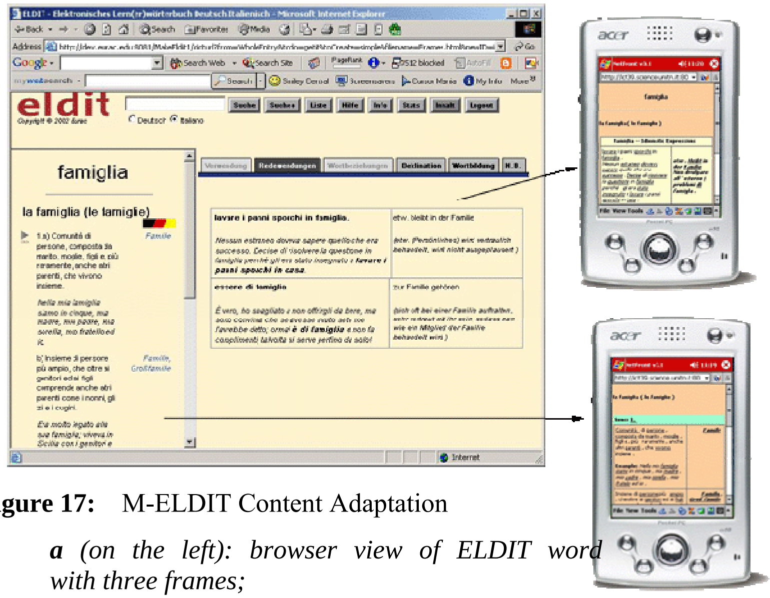


Figure 17: M-ELDIT Content Adaptation

a *(on the left): browser view of ELDIT word with three frames;*
b *(right top): m-ELDIT additional information (idiomatic expressions) for a word entry;*
c *(right bottom) m-ELDIT basic word entry screen.*

We have ‘converted’ the screen on the left of Figure 17a into a series of interconnected screens on the mobile device. When a user wants to see a word entry first the main screen is displayed (Figure 17c). Afterwards the user might select to view more detailed information (Figure 17b) by clicking the links that were added during the XLST transformations on the server. The searching possibility is excluded from the mobile system because, as mentioned before, it would allow the user to request arbitrary words, not only the one connected to previously viewed content. This would force the inclusion of the entire dictionary as the user actions will be unpredictable, which is not desired at this phase.

For supporting offline use of the learning material and for collecting tracking data a client-side proxy is developed. As mentioned before the proxy is responsible for receiving the browser requests and retrieving the content from the server or from the local store (‘cached pages’ in Figure 13) when there is no connection available at the moment. The client-side proxy could also seamlessly upload the content that will be used in the future, based on the prediction done in the ‘Hoarding Engine’.

Generally uploading might be done on a special user request, where the user might also be given an option of setting different parameters, e.g. provisioned disconnection time, expected duration of time in which the system will be used offline, topics preferred by the user, etc. Different other options could be foreseen, for instance the proxy might be aware of the “cost” of the connection and behave in different ways according to that, i.e. synchronizing the cache when the ‘cheap’ connection is available (Internet through LAN or cradle) and using only the cached content whenever possible on ‘expensive’ connections.

Another functionality of the proxy is the tracking of the user’s activities. When connection is available or the device is being synchronized the log files should be uploaded to the mobile Learning Management System (m-LMS). There the mobile version of the user models should be updated and the “Packaging” module will be aware of the user’s needs and adapt accordingly. The m-LMS should be responsible for calculating and updating

the user models, which will differ from the user models in a standard LMS.

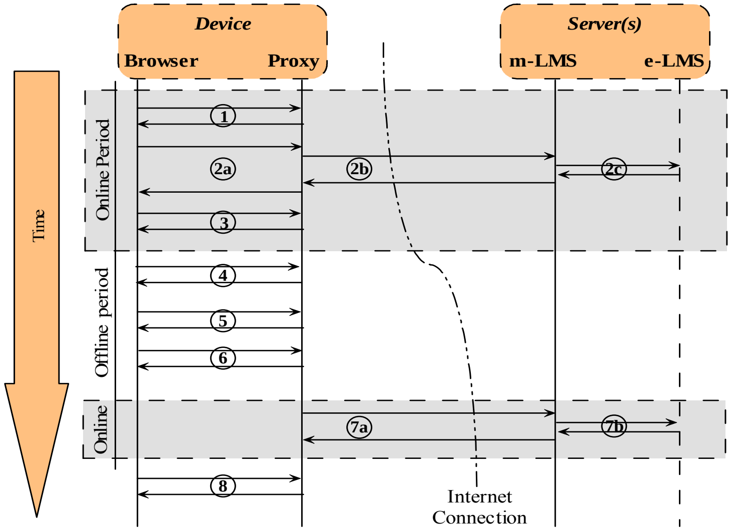


Figure 18: Mobile ELDIT transactions

The Figure 18 above shows an exemple transactional sequence of requests-responses between the mobile device, where the web-browser and the proxy sit, and the two web servers – ELDIT (eLMS) and m-ELDIT (mLMS). The figure shows two online periods (in grey) and one offline period. Steps 1 and 3 show the browser request for a page that is captured by the proxy and, after finding what was requested in its own cache, the proxy sends back the response. On the other hand step 2 shows what happens when the requested page is not in the cache – the proxy sends a request to the Mobile ELDIT server (2b), which on its side gets the raw data (2c) from ELDIT (the XML files), redesigns them and sends the response back to the proxy (2a). Step 7 shows that the proxy might decide to contact the server and to update the content of its cache during the online period even when there is no request from the browser. At the same time the tracking data might be also send to the m-LMS. During all offline periods

(steps 4-6), even if no cache entry is found, the proxy responds to the requests with a meaningful message.

In our real experimentations with Mobile ELDIT the devices were always offline, as the PDA devices we utilized did not have wireless connection. However the implementation of the system supports the step 2b as shown on the figure above. However steps 2c and 7b were never required, as we were keeping a copy of the raw XML files of ELDIT locally on the m-LMS. This was done for facilitating the experimentations, but the scenario described is easily realizable.

The Mobile ELDIT system described here was used by a dozen of self-motivated users, part of which were preparing for the exam of bilingualism and part that was studying and practicing their language knowledge without the goal to pass the exam. The tracking of their requests was gathered and analysed, the outcomes of which are presented further in section 5 - “Contextualization of the Solution and Experimental Outcomes”.

Chapter 4

4. Hoarding: Outline of the Solution

We define hoarding in the learning context as the process for automatically choosing what part of the overall learning content should be prepared and set available for the next offline period of a learner equipped with a mobile device. We can split the hoarding process into a few steps listed here that we will discuss further in more detail:

1. Predict the entry point of the current user for his/her next offline learning session. We call it the 'starting point'.
2. Create a "candidate for caching" set. This set should contain related documents (objects) that the user might access from the started point we have selected.
3. Prune the set - the objects that will probably not be needed by the user should be excluded from the candidate set, thus making it smaller. This should be done based on user behaviour observations and domain knowledge.
4. Find the priority of all objects still in the hoarding set after pruning. Using all the knowledge available about the user and the current learning domain, every object left in the hoarding set should be assigned a priority value. The priority should mean how important the object is for the next user session and should be higher if we suppose that there is a higher probability that an object will be used sooner.
5. Sort the objects, based on their priority and produce an ordered list of objects.
6. Cache, starting from the beginning of the list (thus putting in the device cache those objects with higher priority) and continue with the ones with smaller weights until available memory is filled in.

An effective hoarding system will highly depend on the system's knowledge about the specific user for which materials are to be prepared. Thus the hoarding process should be split into two parts – 1) *the first interaction with the system*, when no knowledge is available about the concrete user and 2) *every next (after the first) access*, when the system has some knowledge about the user and continuously gathers more on each iteration. This system's knowledge includes user preferences, learning style, personal learning abilities, the level of expertise in the studied field and topic. It can be acquired in different ways – by direct assessment of the user, by questionnaires and quizzes, but also by observing and analysing the user behaviour during his/her usage of the system, thus automatically discovering user's learning style, preferences, acquired knowledge, etc. We should point out that our current work is mainly focused on this last mode – automatic gathering of knowledge about the learner important for the hoarding.

4.1. Measuring the quality

An important point is to measure the quality of the hoarding and to try to improve it continuously. An often used metric in the evaluation of caching proxies is the *hit ratio*. Hit ratio is calculated by dividing the number of hits (i.e. found LOs) by the total number of uploaded predictions (cache size). It is a good measure for hoarding systems, though a better measure is the *miss ratio* - a percentage of accesses for which the cache is ineffective. Kuenning and Popek [57] defined a *miss cost* as a main difference in the evaluation of a caching and a hoarding system. In caching/pre-fetching systems the misses in the prediction reflect as a time penalty as the missing content should be retrieved from the web. This differs from the mobile case where with unavailable Internet connection a miss in the hoard might be fatal. In order to quantify this measure it is possible to demand a user rating on every miss, using some different impact values. In some cases of the learning scenario this technique has little sense, because it might be doubtful if we can trust the user's opinion about his/her

own knowledge and expertise and most probably every requested learning material is in fact important for the study process. In [57] is also defined *time to first miss* measure - a simple count between the start of the disconnected operation and the first hoard miss. Note that this evaluation criterion can be used only on real-use of a system (and its hoard part). It is also strongly related to the hoarding size. Another possible measurement is the *miss-free hoard size*, defined as the minimum amount of disc space that a particular hoarding system would require to allow a complete disconnection period to take place without any misses.

The two important measurements that can be used by the hoarding for improving its work on every step are the ‘hit rate’ and the ‘miss rate’. A low hit rate means that the hoarding was somehow ineffective because much unneeded stuff has been cached. The user is never *directly* aware of a low hit rate, but s/he is strongly affected by a high miss rate, since it measures the system’s failure to respond to the user’s requests. Of course the two measures are somehow interrelated: wrong priorities might lead to include some unneeded stuff in place of some useful one, therefore adversely affecting both measures.

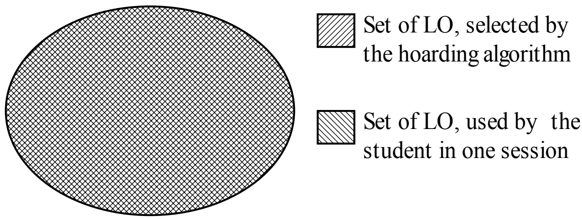


Figure 19: The ideal hoarding set

The goal of the algorithm is to maximize the ‘hit rate’ and at the same time to minimize the ‘miss rate’. The ideal situation is to achieve hit_rate=100% and miss_rate=0%, which would mean than the hoarding set contains *all* and *only* the items that the user needs during her/his studying session as shown in Figure 19 above. Of course, a hit rate lower than 100% would be acceptable as long as the miss rate remains at 0: it would only imply a sub-

optimal usage of the available resources (i.e. a waste in memory) without affecting the perceived system performance.

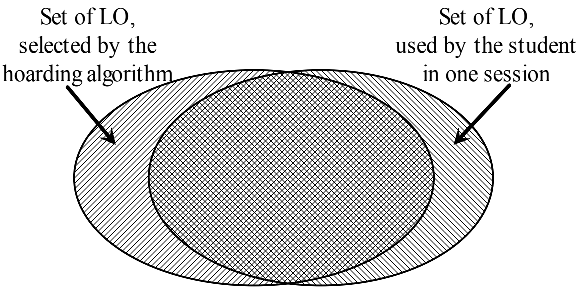


Figure 20: The expected picture

Though the ideal picture (Figure 19 above) is to select all and only those items that will be used by the user it is obvious that in a real system such an ideal situation is almost impossible to reach. Most probably we will have some (desirably big) overlapping between the cached by the hoarding algorithm LO and those LO really requested by the learner (see Figure 20).

As mentioned before the hoarding sub-system should be able to analyse how successful was the previous hoarding and improve its further predictions. For this we should be able to check which parameters or combinations of parameters of the user model and/or domain knowledge have bigger impact on the goodness of the algorithm.

By analysing the goodness of the prediction of the hoarding algorithm we can try to tune its work. For example if a user indicates a LO miss as fatal the algorithm should check why this LO was not cached, e.g. if this entry was pruned or was given a small priority, and later the ‘rules’ for pruning and/or prioritizing should be reconsidered accordingly. This is actually one of the particularities that mobile learning offers. Often mobile devices are definitely personal devices (used only by their owners or, as in the Mobile ELDIT application we developed, are borrowed for certain period of time, but used only by one person during that period) it is possible to easily and securely identify the user.

4.2. Definition of session in the mobile learning context

In the Internet world a session is defined as “a continuous period of time during which a user's browser is viewing Web pages or a Web application within the same server or domain” (source - MSDN Library). It is a series of transactions or clicks on the web pages links made by a single user. There are different criteria to decide if a session is over or not. The most commonly used one is the inactivity period of the user: resumption of the activity by the same user after a timeout has occurred is considered as the start of a new session.

On the other hand for hoarding in a mobile system the importance falls on the time between two possibilities of the user to synchronize with the main server. In this sense we find more useful to define a session as the time between two synchronizations of the mobile device with the main online system. The default session length might be one day, as commonly synchronization is generally done once per day, but during the system usage other session lengths might be observed and explicitly set for every user.

Further we will use the term “single session” to indicate the first definition above, while we shall use “session” to indicate the hoarding-related meaning. We will also speak of “daily session” to mean all the activity that has taken place in a calendar day.

4.3. Hoarding on the first access to the system

Earlier we mentioned that the hoarding process differs on the first access of a user to the mobile system. This happens because we do not ‘know’ this concrete user and his/her particularities. Nevertheless most of the steps of the hoarding should exist, although they will be a little changed. We still have to ‘predict’ the starting point, to generate a candidate set and to try to sort the objects in this set, but in this first access of the user the hoarding sub-system should calculate and use some default values, extracted by analysing the behaviour of all previous users of the system. If the mobile application is an addition to an online e-platform it is possible

and even desired to see if some knowledge could be extracted about the user from the e-learning system and use it instead.

Let us start with the learner's entry point. Often learning material is created by the educator with a certain sequence in mind. Thus, based on the additional knowledge about the learning material structure, the system can be aware of the most probable starting point of the students' first session. This might be an index page or a list of all lectures of the course. Based on the observations of all previous users the system can be aware of often used sequences of material used on first request and can also estimate the average or maximum depth, in which the students browse during their first session. Still it might be that users have very different behaviour. In the context of pre-fetching the content on the first user access the system should hoard as much as possible data trying to satisfy all user's requests, as shown on the figure below. In a system like m-ELDIT this means to deliver only a limited amount of basic data (texts) and much auxiliary material (dictionary entries).

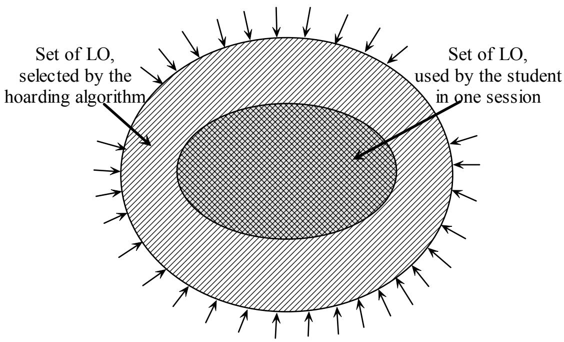


Figure 21: The hoarding starting step

The system can try to detect the user expertise level on the study topic (by a questionnaire for example) and to narrow the hoarding set using some domain knowledge, e.g. if certain material should be proposed to beginner users, and if the current user is advanced, the material should be excluded from the hoarding set. An initial evaluation of the user knowledge could be provided by the educa-

tor assessment, though it is out of the scope of this work. As we are mainly interested in extracting automatically important knowledge about the user, we would like to look at the tracking data of what the learner accessed. In some cases might be possible to consider (with a certain confidence) that a portion of the material which the student reviewed is mastered, or we can do some mining based on how long the user needed to review this particular portion. In other cases it might be very important to look also at what the learner could access, but decided not to view.

It is important to consider that on the first interaction the user is commonly unfamiliar with what can be done, what interactions are allowed, what will be received on different actions, etc. This means that user actions might be based on his/her curiosity, rather than driven by his/her knowledge or by the content. This leads to the assumption that the mining on the data gathered by the system on the first user knowledge should be more attentive and extracted rules might be unreliable.

4.4. Predict the starting point

As mentioned in the previous section the web-based learning material provided by an educator will generally be structured in some manner and will have a certain starting point or index page (shown on Figure 22).

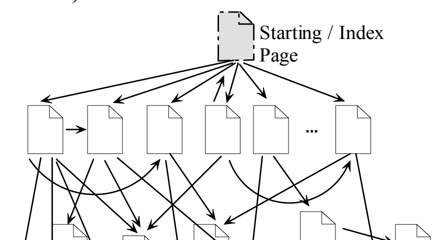


Figure 22: Web-based material structure

This is the starting point of the learner for his/her first learning session with the system. It can be also often a starting point of every following session, especially if this index page contains an ordered reference of other materials, like lectures sequences, exercises, etc. A possible approach for predicting the starting point of user sessions is to keep statistics on what is the starting point of a session considering what the end-point of the previous session was.

Our initial experiments on mobile ELDIT (see Section 5.3.2) show that after the first learning session (which we consider almost unpredictable and rules that could be extracted by analysing it are unreliable) the users generally show a very 'coherent' behaviour – if a list of materials is presented to a user he/she almost always starts from the first item of the list, then goes to the second, to the third and so on. It is also valid for the sessions - the user continues from the point where he/she finished last time. This rule is rarely changed and if it happens it is based on some specific interest of the user. For example we were giving a list of texts that were thematically grouped and the users were generally browsing starting from the beginning of the list. In infrequent cases when a certain topic was especially interesting to the user he/she was skipping the previous subjects and reading directly what was of interest and later returning to what was skipped. We can not be sure that in every kind of learning material the users will show the same sequential behaviour. We however believe that supposing a continuous user browsing is a good starting point for hoarding predictions whenever an instructivism approach is applicable. It should be also mentioned that in our scenario the material (the texts) were just listed and not specifically ordered, which allows to the user the freedom to navigate as preferred. Still the users show this consecutive browsing behaviour. In contrast with our system often for reading certain material there is a pre-condition, given by the educator, that the user should be already familiar with the previous topics. Depending on the mobile learning system additional information about those

pre-conditions can be known to the system and considered in the predictions. Evaluation of the user competence on a subject will surely contribute.

4.5. Generate 'candidate' set

As mentioned earlier, one of the steps of the hoarding algorithm is to construct the 'candidate' set of learning objects to be hoarded. When using web-based material the user clicks on the links of one page to go to another one and can either continue to browse further or can go back to a previously viewed page (Figure 23).

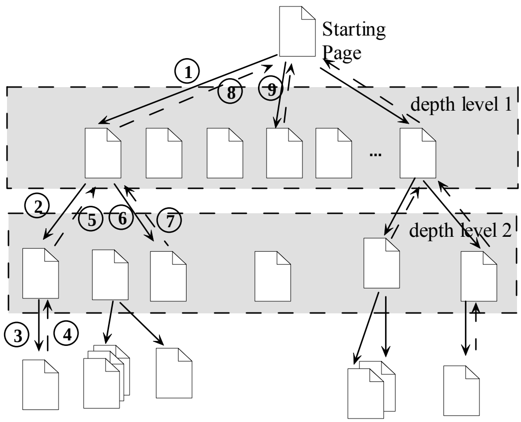


Figure 23: Browsing path

This means that the candidate set should contain the objects linked to the starting point, i.e. the objects that the user might decide to visit. Further it should also contain the objects that are linked to those objects that the user will access and so on. The construction of the candidate set should be up to the depth level that is generally reached by the user. For the first access this value can be taken as the average (or the maximum) depth of all previous first sessions.

The links between the pages give us the structure of the web site (a learning material in particular), thus we can extract the links between the LO by parsing the pages and keeping this data

in a more useful format for computations. These links might be either bi-directional or not. We can build a table that represents these links in the way shown on Listing 1.

Listing 1: Creating the LO links table

```
for (every LO) {
    create a row;
    for (i=1, number_of_LO, i++) {
        if current_LO contains link to LO_i
            set cell_i = 1;
    else set cell_i=0;
    }
}
```

An example table that can be a result from this algorithm is shown on Table 1. On the first row one can see that LO_1 contains link to LO_2 and to LO_n , but not to LO_3. There is a bi-directional link between LO_2 and LO_3 (see row 2 col. 3 and row 3 col. 2). In this way we can easily observe the set of objects that the user will be possibly requesting if he/she decides to browse deeper in the site, i.e. to go one level of depth further. Those would be the objects directly linked to a particular object. From this table we can easily construct the 'candidate' set for every next step/level of hoarding. Later this candidate set will be pruned (its size can be decreased by dropping some of the objects that are not likely to be requested).

Table 1: Links between LO

	LO_1	**LO_2**	**LO_3**	**…**	**LO_n**
LO_1	x	1	0		1
LO_2	0	x	1		1
LO_3	1	1	x		0
…				x	
LO_n	1	0	1		x

The generation of the candidate set should start from the starting point, predicted for the next offline session. It should generate a 'candidate set' of the LOs connected to this point and afterwards should be followed by pruning of those candidates. When the pruning of this depth-level-1 candidate set is finished a candidate set should be generated for every LO that is still in the set, thus going one level deeper. Again pruning should be done on the newly generated candidate set and the cycling procedure should stop when the estimated user's browsing depth is reached.

4.6. Pruning

Pruning is the step when the hoarding system decides if a LO is probable to be seen by the user or not and in this latter case excludes this material from the hoard. This should be considered the most important (together with prioritizing) step and at the same time the most fragile one in the hoarding process. An alternative to the pruning might be a prediction of the exact path that the user will be following, but in a real system (unless a very strict following of the learning sequence is required by the educator) this would be almost impossible.

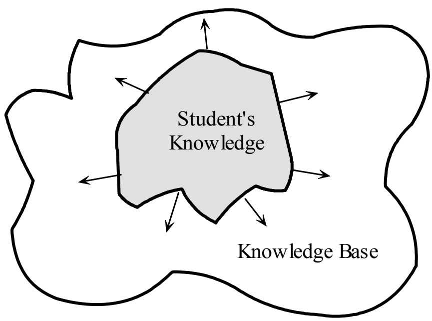


Figure 24: User knowledge as a subset of the knowledge base

Pruning should be done of LOs that are not interesting for the user and of those that the user already knows/have mastered. One possible schema is to determine the user knowledge by assessing him/her at the beginning of the learning with the system. For the

purpose of the algorithm the user knowledge is always a subset of that provided by the system knowledge base (see Figure 24). By a well defined questionnaire the system might determine with a good accuracy the user knowledge set.

If the system does not provide any initial assessment then the user knowledge set is empty at the beginning. Nevertheless the goal of any educational tool is to increase the students' knowledge over the provided knowledge base, so in general the set representing the user knowledge should be dynamic - continuously growing. If some particular exception is not determined, then the system should prune the LOs that are in the knowledge base of the student. At this point is already clear that it is very important to correctly determine what subset of all knowledge base is the student's knowledge.

In our Mobile ELDIT system we decided not to test the user knowledge at the beginning but rather to try to automatically gather this information by analysing the user browsing behaviour. We did pruning of the LOs based on our supposition that the user knows a certain LO.

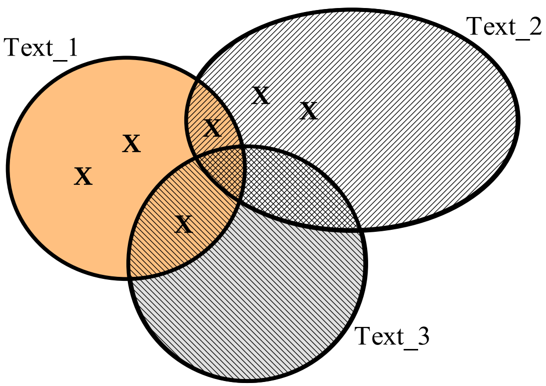


Figure 25: Overlapping of LO accessed from different locations

It was previously mentioned that our data is very low-granulated – up to a word entry, which are the LO in this case, thus we have some overlap in the data that can be accessed from different locations (e.g. the same words will be presented in more than one

text). On Figure 25 we schematically show the LO sets of three texts. The X-symbols show the words that the user requested to see when reading the text in which the X belongs. At the first user access we did not have any knowledge about his/her language skills thus no pruning was done. If the user was reading on the first session Text_1 and it was predicted that for the second off-line session Text_2 should be prepared then we can prune the LO that the user had the possibility to access the last time, but decided not to do it. Thus we subtract from the whole set of LO for Text_2 the words that we consider the user knows.

It should be pointed out that it is possible that the user only opens a page with a text but doesn't really read it. In such a case the LO that were contained in the set will be wrongly considered as known by the user. Thus this elementary rule might be too simple and lead to big hoarding miss-rate. If used with a combination of other rules the accuracy of pruning should be noticeably higher. For example one can look at the time needed for reading certain page: if the time was below a given threshold, the material can be considered as not read.

4.7. Prioritizing

Setting the priorities to the LO that are still in the hoarding set after the pruning process is also a very important step. This is because even when pruned the set might be still bigger than the available mobile device memory and only part of it will fit in. The priorities in the hoarding context should mean how important the object is for the next user session and should be higher if we suppose that there is a higher probability that an object will be used sooner. In this sense the predicted 'starting point' of the user's next offline session should be always assigned a maximum priority.

For prioritizing the LO we can analyse the accesses done previously by all the users and extract interesting and important knowledge. Aggregated data, like the correlation between the objects, based on their contemporary usage in other users' sessions is one thing that can be easily discovered, and is very helpful. For

example a well known association rules (see [36]) discovery can be applied to determine from all previous learning sessions the relations between LOs that are ‘very strong’, i.e. associations discovered with confidence near to 1 and big enough support value. Note that when searching in the full tracking data set it is expected that not a lot of such associations will be found, as the common scenario is to have big variety of LO and also big diversity of students’ knowledge, interests and learning preferences. The rules extracted in this way will be of the following type: $LO_i \Rightarrow LO_j$: conf=0.99 sup>0.5 which we can read as “Almost every time when the LO_i was viewed by some user also LO_j was viewed in the same session. An example can be that LO_i is a problem given to by the educator the students to practice the comprehension of certain material studied and LO_j - the solution given also by the lecturer and linked at the end of the lecture)”.

Table 2: Example of sessions and requested LO

	LO1	**LO2**	**LO3**	**LO4**	**LO5**	**LO6**
Session1	0	0	0	1	1	1
Session2	1	1	1	0	0	0
Session3	0	0	0	1	1	1
Session4	0	0	1	0	1	1
Session5	1	1	1	0	0	0
Session6	1	0	1	0	0	0
Session7	1	0	0	0	1	1

For the example we can pre-process our tracking data (the user’s clicks recorded on the mobile device) into the data shown in the Table 2 above. Every row represents a single session (not taking into account to which particular user it belongs). In every cell 1 means that LO_i was viewed during $Session_j$ not taking care of the sequencing. For this data association rules algorithm will discover with confidence=1 the following relations:

$LO_2 \Rightarrow LO_1$; $LO_2 \Rightarrow LO_3$; $LO_4 \Rightarrow LO_5$;
$LO_5 \Rightarrow LO_6$; $LO_6 \Rightarrow LO_5$;

Association rules can be discovered also in more limited number of sessions (not all at a time). For example one might search for correlated objects only in the sessions of users that were classified in the same group of content interest or field expertise. Considering again the example data in Table 2 if we apply a clustering algorithm (like k-means) (see again [36]) the algorithm will produce 2 clusters. We marked the rows that would be in different clusters with different shades intensity in Table 2 – $cluster_0$ in grey and $cluster_1$ in white and we represent them separately in the first two columns of Table 3. Applying association rules only to the sessions in the same cluster we get some additional associations. The clusters and discovered associations are as follows:

Table 3: Associations found for clusters of sessions

Cluster	**Instances**	**Additional Associations**
$Cluster_0$	$Session_1$ $Session_3$ $Session_4$ $Session_7$	$LO_1 \Rightarrow LO_5$ $LO_3 \Rightarrow LO_5$ $LO_3 \Rightarrow LO_6$ $LO_4 \Rightarrow LO_6$
$Cluster_1$	$Session_2$ $Session_5$ $Session_6$	$LO_1 \Rightarrow LO_3$ $LO_3 \Rightarrow LO_1$ …

The above associations (like $LO_1 \Rightarrow LO_5$) show that if LO_1 is to be selected for the hoarding set there is big probability that the user will also be accessing the object LO_5 during the same session. Moreover associations of the type LO_5=1 & LO_6=1 $\Rightarrow$ LO_2=0 can also be discovered, showing that if the user will be viewing objects LO_5 and LO_6 it is most probable that the object LO_2 will not be viewed. This in some cases we can lead to increasing the set priority of certain material, while in other cases we can set it to much lower level which will sometimes lead also to exclusion from the hoarding set.

Note that for the example above we considered only associations with confidence=1 and any support greater than 0. In real

situations the best values for these parameters should be experimentally discovered. Generally the confidence value of the discovered associations can help also in placing the items of the 'candidate set' in an ordered list.

Also other data mining and/or machine learning algorithms should be considered and tested to see their appropriateness for the hoarding process and how they can be combined best.

When no other rules can be applied the possibility to fit the predicted set into the limited device memory should be checked. If there are still too many LO with the same priority that are predicted to be uploaded, the choice should be done randomly.

4.8. User modeling

There are different ways to model user behaviour depending on the application and its needs. In the context of hoarding we recognize two groups of characteristics that will be used differently in the hoarding process. We schematically call the first 'user behaviour' and the second 'user knowledge'. Additionally there could be another group of characteristics, that we call 'user preferences' which is not substantial for the hoarding at this stage, thus we do not discuss it here. Depending on the mobile learning system it is possible that not all the parameters can be discovered or they might be discovered through different techniques. The data about the user might be obtained by (any combination of) questionnaires, tests and quizzes or automatically by tracking the user and analysing the log files. The process for retrieving automatically the information about the user should consist of few steps, like preparation of the data for analysing and application of different knowledge extraction algorithms. During the first one the log files are pre-processed and integrated into a database and afterwards, in the second step, interesting relations and deductions are found.

The *user behaviour* can be described in terms of browsing styles (e.g. consecutive, random, interest driven, etc.); preferred type of educational media (e.g. prefers video to combination of text and pictures); speed of read/study (fast, medium, slow), etc. Based on

the user behaviour we can group the learners and do mining based on the similarities and differences between the groups and between the members of the same group (shown in previous sections). This should help us mainly to predict what will be needed, i.e. this data will be used to fill-in the hoarding set or in prioritizing the LO.

On the other hand the *user knowledge* profile should consist of everything that the system knows about what the user already knows. Example is the system awareness of the user's competence in a certain subject (i.e. beginner, intermediate, advanced) or a list of all the topics already covered by the user previously. Users can be also grouped based on their knowledge, but in contrast to the *user behaviour* the profile of the *user knowledge* will be mainly used for pruning the entries from the hoarding set, i.e. for excluding objects in order to decrease the size of the hoard.

We can distinguish static data about the user and dynamically changing data. The static data include for example the user age, gender, mother tongue and etc. On the other hand the dynamic data is our current knowledge about the changeable over time user parameters and should be reviewed in certain periods of time. For example the user browsing pattern might change drastically few days before an exam date, thus the hoarding system should be able to quickly recognize such changes and react accordingly.

Chapter 5

5. Contextualization of the Solution and Experimental Outcomes

The previous section gave the outline of the strategy for solving the hoarding problem in a general level, outlining some of the techniques that are possible to be used in concrete implementations. What we describe till now gives more abstract view to the solution and is general so that it would be valid not only for our system, as the concrete implementation might differ from case to case and in our view will often depend on the concrete system's specifics. In this section the way we mapped the algorithm discussed before to the actual implementation in Mobile ELDIT will be described. Both measurements and observations that we obtained from experiments on the system are provided.

5.1. Methodology for looking at the outcomes

We have clearly shown by now that this thesis has the main goal of attacking the hoarding problem. In the previous section (4.1) we described how we plan to measure the goodness and success of our hoarding strategies, in terms of hoarding size, hit rate and miss rate and we discussed pros and cons of other possibilities.

However the supplementary goal we have in the current work is to analyze the successfulness of the newly developed mobile learning system – Mobile ELDIT (see 3.3) from a less technical point of view and to gather experience for further improvements. For this we have performed questionnaires and interviews with the users of our system at different stages. Initial surveys have been performed for determining the students' previous experiences with similar systems, with computational and mobile devices in general and expertise in the targeted languages. Additionally a questionnaire was filled-in by the users in a later stage,

when they were familiar enough with the system, to evaluate the system in terms of ease of use, usage preferences, etc. Users could propose further improvements and discuss disturbing factors. Some of the described problems, difficulties, opinions and suggestions were gathered by face-to-face discussions during the experiments. Interesting and important points are reported further in the chapter.

5.2. Automatic extraction of knowledge about the user

The process for retrieving automatically knowledge about the user is shown on Figure 26. It consists of two main steps: 1) preparation of the data for analysing and 2) applying different algorithms for automatically extracting interesting knowledge.

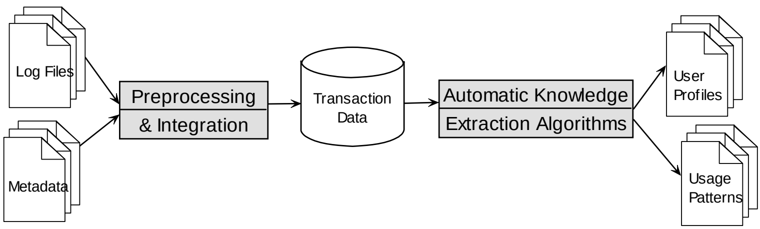


Figure 26: The process of extracting knowledge about the student

By “data” we mean the log files where the user interaction with the system is saved plus any additional data about the learning material itself, about expected user behaviour, known logical grouping of the users and etc. In our particular case the data consisted of the tracking data gathered by the on-device proxy and the raw XML data files, from which we extracted the structure of the learning material.

Before describing details of our approach to analysing the data gathered from the Mobile ELDIT we should once again mention that the common ways to determine the user characteristics and knowledge (generally in e-learning systems, but also in m-learning) are assessment through questionnaires, quizzes and tests and letting the user manually set his/her own preferences. Our re-

search interest though falls on the automatic discovery of these attributes and for this reason we were collecting the same tracking data as a normal/standard proxy would collect. It is obvious that the user knowledge of a concept determined by assessing him/her and checking the tests results, especially if a human-teacher is involved, can commonly give some quite precise quantified measure of the learner understanding and advances in the chosen subject. On the other hand by analysing only the user's interaction with certain system might give less precise approximation, but might sometimes makes life easier.

As one can see on Figure 26 above with the help of different algorithms for knowledge extraction we expect to get two types of data – on one side are the different typical usage patterns that we need to extract out of all available data set and on the other side is the understanding and categorization of every concrete user. It should be possible to automatically extract knowledge for all three groups of user modelling parameters discussed previously in Section 4.8, e.g. *user behaviour*, *user knowledge* and *user preferences*. Nevertheless extraction of knowledge about *user preferences* is out of the scope of the current work.

The pre-processing of the raw data on one hand is the process where the log files and all other available data should be parsed and integrated into a database or other suitable format to perform knowledge extraction algorithms. Generally the pre-processing is one of the most resource consuming processes, but in the context of analysing user behaviour in a mobile learning system this part might be on the server and will most likely be performed during the offline periods of the user. This means that in our context this is not a critical point, e.g. even quite slow speed of the pre-processing and extraction of the data will not lead to user's impression of a slow system.

As we previously discussed the optimal way for developing a mobile learning system is to make it sit on top of an e-learning solution, in such a way that to take advantage of what is provided there already. In section 3.3.3 we showed that our Mobile ELDIT uses the same XML data with the online ELDIT, substituting on

the server side the ‘Content Redesign Engine’ with a specific one for the mobile devices– this was one of the general principles described in Section 3.2. Further, one of the very important functionalities for the hoarding process of the m-LMS is the possibility to analyse the user behaviour, based on the system usage. In this sense one should take also here the advantage of the possibility to analyse and extract important knowledge about the user by using the information from the tracking data that is possibly gathered in the e-LMS. This is especially important when the same user might be using the online and the mobile version of the system in the same period of time, but it might be also useful to get familiar with the general behaviour of the users in the system itself.

5.2.1 Approach 1: using the online desktop system

In our case this approach was inapplicable, as we met the problem of identifying the users of the online system. In ELDIT there was no specifically developed tracking subsystem on the server and a number of different servers were responsible for different parts of the platform, like authentication, content generation, collection of statistical data and etc. Another particularity was that for accessing the online ELDIT the user had to register and log-in, but in practice the system was developed in such a way that the users were not obstructed to register with different username on every usage. As tracking the users was not one of the objectives of ELDIT it seemed not to be a problem for the online system. On the other hand this led to the impossibility/uselessness of analysing user behaviour based on the online system which to be used as a basis for the mobile version. This pushed us to the second possible approach, namely analysing and extracting knowledge from the log files gathered *only* on the mobile system.

Nevertheless it is important to have the awareness that the user behaviour on the online desktop system might differ, sometimes even drastically, from the one that the user will have on the mobile system. In fact in the interviews we had with the users of the Mobile ELDIT that were familiar and were using also the

desktop ELDIT people share those differences and we report them further on in Section 5.4.

5.2.2 Approach 2: using the mobile system

One of the advantages that mobile learning gives us compared to e-learning is the possibility to easily distinguish one user from another. In e-learning environments the problem of having multiple users using the same computer or the fact that often the users are behind a proxy server is generally solved by asking the user for username and password on every session. In a mobile learning system one can have the advantage that the mobile devices - cell phones and PDAs are very personal devices, generally used only by one person, thus the problem of identifying the user, which often appears in web based systems, is much looser here. The log files might be collected on the server-side (mLMS), with bigger certainty for correct identification of users than in the general e-learning case, though the problem of the device being behind a proxy still exists. However in this case the offline periods will not be covered. So we found a much better solution in conveying the tracking task onto the mobile device - the tracking data is stored locally and when connection is available is transferred on the server. In Mobile ELDIT the user was asked to give some initial information about himself only on the first interaction and later is freed from any direct interaction with the system. In this way the identification of the user is done once, when the system is set-up and is included into the log files name.

* URL	Date	Time	Delay
TextsList	19/11/04	19:10:02	1
it.c.general.032	22/11/04	10:06:25	1
it.n.accoglienza.1.deriv1.pbs0	22/11/04	10:07:25	1
it.n.accoglienza.1.full	22/11/04	10:07:47	6
it.v.compiere.1.lemma	22/11/04	10:10:10	1
it.v.essere.1.lemma	22/11/04	10:10:56	0

Figure 27: Log file collected from the device-side proxy

The architecture that was developed for the mobile ELDIT and described at Section 3.3.3 comprises a client side proxy (see Figure 13 on page 56), which collects the tracking data. The user

interactions with the system are written into log files and contain the visited URLs on the mobile device together with the date and time when the links were clicked, as shown on the Figure 27 above.

For our system a database was created where the needed data to be hold, including the tracking data, aggregated values and etc. From here later was easier to extract portions of the data, which were fed into the knowledge extraction algorithms. The database, shown on Figure 28, is composed of two logical parts, which are actually interconnected – one is the data about content (the upper part on the figure) and the second is the pre-processed tracking information (the lower part on the figure).

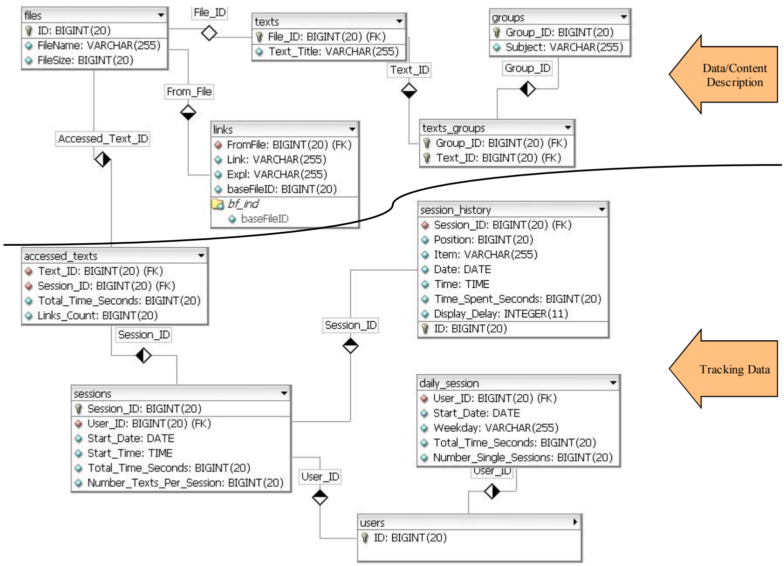


Figure 28: Database containing the content data description and user tracking information

The pre-processing of the content of Mobile ELDIT consisted of parsing the XML files of each text and word, earlier created by the linguists of ELDIT and from there we extracted all possible links. Every file, text, word and link was assigned an id, and the

tables were linked with foreign keys, used afterwards for easy querying. On the other hand, the pre-processing of the log files consisted of:

- Generating missing history values;
- Identifying separate user sessions;
- Calculating times;
- Calculating accumulative values.

Generating missing history values: As explained earlier we used as interface to access the learning material of ELDIT a standard web browser on the PDA device, which requests were captured by the local proxy and were written into the log files. A particularity of the browser is that it keeps cache of the pages already requested in the same day. It leads to the fact that in the log file the history is not full, for example the pressing of the back button by the user, and thus viewing once again a page is never written in the log. A particularity of the usage of PDA devices explained in the next paragraph leads to almost the same result, even if the sessions' separation was made precisely. The log file might sometimes be incomplete and miss the reference point for some of the links. While in the first case there are no problems during the post-processing and knowledge extraction phases in this second case some obvious inconsistencies often appear. For example if the first request of the day is for a word, it is obvious inconsistency, as the words in Mobile ELDIT are always accessed by clicking inside a text. By using some heuristics the appropriate text entry should be added to the log file.

Identifying separate user sessions: This is a very important (as explained previously in Section 4.2) and turned to be not a so trivial step. It was necessary to apply some heuristics, like to choose the single session time limit or the inactivity period after which the session is considered over. Important to mention is that PDA devices, in contrast to desktop PCs and laptops, are used in quite a different manner. For example they are never switched off and users generally leave all applications open, thus often even after one day interruption the user was starting to work from the same point where he/she suddenly was interrupted.

Calculating times for which every requested URL was viewed: In most of the cases this was the time difference between the time of the request and the time of the next request. Nevertheless this simple rule can not be applied in some cases, like for the last page in the session, as there is no ‘next’ request. In such a case we were using the calculated average time of the requests in this session. However other rules could be used, like average of the times of all requests of the current user or the averages of all requests. As the different strategies did not impact much the values calculated for Mobile ELDIT content and this factor did not seem to have great importance up to the current stage of our experiments we did not test in depth different possible options.

Calculating accumulative values: In order to facilitate further exploration we included into the database also some additional information extracted from the log files, like for example the time spent on every single text, total number of words requested from each text, number of texts viewed in every session, total time of the session, number of interruptions of a daily session and etc. Some of these values were later used in the experiments of automatically grouping the users. It should be mentioned that this step was very sensitive to the way previous steps were done.

In practice the real experimentations with Mobile ELDIT started in June 2004 with three mobile devices - an iPaq H3800 and two Acer n10. All devices are Windows CE based. Up to now we have observed 12 users for longer period of time and about 16 non Italian-speaking persons participated in a few-days experiment. Some of those in the first group used the system for few weeks period, just before their exam of bilingualism. Others utilized it for much longer period – almost a year, thus that we can have more data and try to analyse also evolving in their behaviour. All this data has been put into the database, as shown above, which later gives a possibility to easily extract portions and converting the data into a format, appropriate for every specific knowledge extraction algorithm.

5.3. Hoarding results

In our hoarding experiments with Mobile ELDIT system the usage data was collected in the following manner: as a first step the users were given a set of ELDIT texts and were asked to study them at their convenience. Whenever the users felt that they had 'finished' with the current portion of texts they were given another set. As mentioned before part of the users were preparing for the bilingualism exam, others were just studying the language, without aiming at passing the exam. Only in certain cases the users were given the option to choose the texts they would like to read. Nevertheless whenever the full data set was not fitting device memory the sets of words were chosen randomly. Our initial hoarding experiments had the aim to explore the basic hoarding system that uses very simple rules for the pruning and has shown that the hoarding will really work. Step by step we tried to use more complicated rules and to add intelligence to our system, thus to improve the hit_rate and to decrease miss_rate (see Section 4.1). Later steps were based on in-depth user behaviour observations. Some interesting and important outcomes from those experiments, which are not directly related with the hoarding process, can be also found at the end of the section.

5.3.1 One User Hoarding

For obtaining the first hoarding results we observed only one user at a time. We gave to the user a short list of available texts and we considered this to be always the user 'starting point', as described in the general algorithm (discusses in Section 4, see page 79 for reference). Then, for creating the 'candidate set' we selected all the words that were accessible from the chosen text and then we did pruning, based on what we thought the user already knew. One can see that in this experiment Step 1 was solved in the simplest way – limiting the user choice to a small number of texts which were all pre-fetched on the device and thus eliminating the need to predict the starting point. Our goal was mainly to test the automatic pruning which meant essentially to discover automatically the user knowledge set. We used the following assumption:

the user knows all the words that were presented to him/her in a previous text, and whose links were not followed. In this way on every next iteration more words were pruned and the hoarding set was smaller.

On Figure 29 we show how the hoarding set is getting smaller for one of the users of the system. We have chosen a participant with very common behaviour to demonstrate the general ideas and further we discuss some particularities we noticed in other users' behaviour. On the figure below the x coordinate is the step for the calculations, which we chose to be one text; the dots in the lower part show the real user requests; the squares represent the size of the hoard and the line shows the trend of how the hoard decrease with every next text that the user was reading; the triangles show the miss rate (calculated as the percentage of accesses for which the cache was ineffective) if it is not zero.

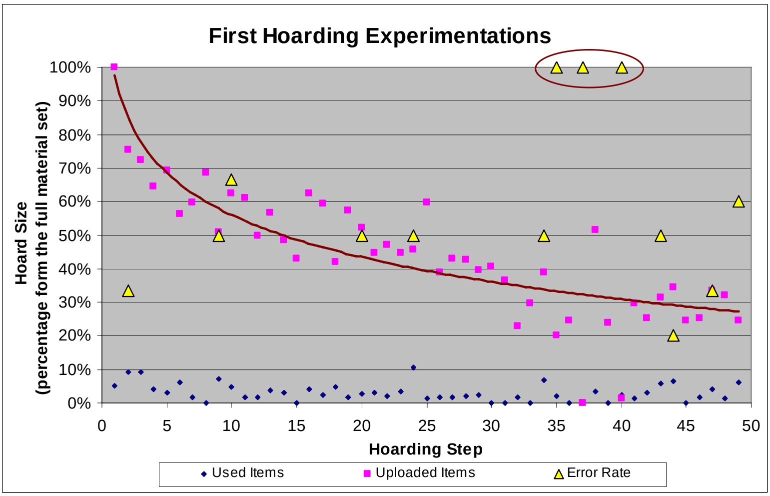


Figure 29: Example data showing the decreasing of the hoarding set

First of all, the graphic on Figure 29 shows that hoarding process works, even in this rough first iteration and the very simple pruning rule we have used here. One can see that within 50 steps the hoard size decreased to about 30% which makes the hit_rate from about 5% on the first step to grow up to 25%. Even though we

have used a rather simple rule for pruning – what we consider that the user knows, we see that in 75% of the cases we have no misses, which is quite good correctness. Nevertheless at the next step we should refine the algorithm and to improve it in the following two directions:

1) To make the hoard decrease faster and
2) To assure that the algorithm works more precise.

To make the hoard decrease faster (i.e. in fewer steps and with bigger values) we should combine the knowledge gathered from other users' usage data. This means that we have to analyse the similarity between the users. For similar users (for example similar in their proficiency on the studied subject) we can guess that a user knows certain word, based on our awareness that the other similar user (or users in a group) knows it. In contrast with this first experiment, where we considered a word familiar for the learner only when he already had the possibility to see it, in a further trial we will try to guess in advance.

On the other hand one can see from the figure that in some cases we have a big (sometimes 100%) miss rate. We have mentioned earlier that for the mobile learning scenario the accuracy is very important. This was also proven by a questionnaire that our first users filled-in, where almost 100% mention hoarding misses as the most disturbing problem of the mobile system. A miss in the hoarding might lead to termination of the study process or even worse to misunderstanding of the material. We have to assure that the algorithm works more precisely.

One of the main reasons for errors of the hoarding algorithm is the simplicity of the pruning rule that we have used in the current experiment. In the cases that we have obtained 100% miss rate (cases are shown with a red line surrounding them) the reason was that the user had requested a text and without reading it pressed the back button and continued with other material. This misled the algorithm to 'conclude' that the user knows all the words that were provided in the text. This in its turn led to excluding those words from further including in the hoarding set. Later on the user requested the same text again, this time really

reading it. As the algorithm already had decided that all words are known to the user and excluded them, every word requested was missing. This problem can be solved by monitoring the time spent on a page, so as to be able to infer whether the page was actually read. Later on in the section 5.3.2 “User behaviour observations” one can see that in Mobile ELDIT a common time needed for reading a text is more then 3 minutes, so if the time spent on a text is less then 180 seconds the user most probably did not really read it.

5.3.2 User behaviour observations

The main objective of the thesis is to support automatic analyses on user behaviour and using the extracted knowledge in the hoarding process. Nevertheless, as there was no previous research in the particular context described above on which we could base our experiments we were forced to combine the automatic knowledge extraction with semi-manual and manual analysis, combined also with some questionnaires and interviews with the users of our system. Based on them we extracted some important knowledge and characteristics that were further used for improving the automatic hoarding or for confirming the correctness of the knowledge automatically extracted. In order to be clear further we list them here and give details right afterwards:

- Measurements of the overall usage times and number of texts read in a single session
- Noticed random behaviour on first access
- Noticed consecutive browsing behaviour
- Reported changes in the behaviour with time
- Reported importance of missing words
- Noticed different importance of different types of words
- Reported usage of additional material and notes taking
- Noticed differences based on the target language

Overall times and number of texts read in a single session: Generally people were using the system between 10 and 40 minutes. On Figure 30 we show the session length distribution that was extracted automatically from the system. Important to know is that

the users preparing for the exam report spending longer periods on every single text (30-40min) as they were picking up more word entries, since they were trying to answer the comprehension questions. This means that on average one text was read in one session. Others that want to improve their language skills might read certain texts in 3-5 minutes, thus reading more texts in a session. Sometimes (rather rarely) a user was reading a large number of texts (see Figure 31) for a longer period (> 1h.).

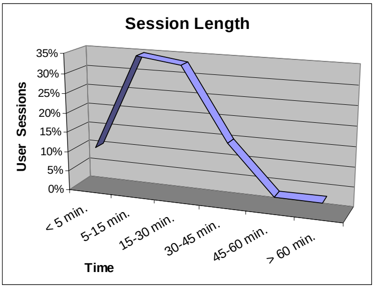


Figure 30: User session length in Mobile ELDIT

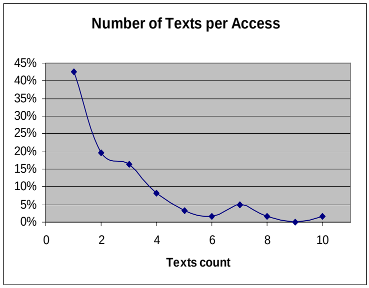


Figure 31: № of texts read in one m-ELDIT access

Random behaviour on first access: The final goal of our experimentation is to support the automatic selection of learning material for offline periods. For this we need to be able to predict what material the user will need in his/her next learning session. Our observations show that during the first use of the system the learner is exploring what is possible to be done in this unknown environment, so his/her actions are quite unpredictable. For example it is very likely that the user will click on a word that he/she is familiar with just to see what information is available. This leads to the impossibility to exclude even easy (basic) word entries (e.g. the word '*essere*' – '*to be*'). Later on, the users start really studying and do not click on words that they do not need. Also deductions of the student's knowledge should not be done based on this first access, as they might be misleading.

Consecutive browsing behaviour: A very interesting observation is that most of the users show a strict consecutive browsing be-

haviour (Figure 32). We expected that the users will read groups of texts in different order depending on their mood or specific interests. However generally they were reading the text in order of appearance in the list we provided.

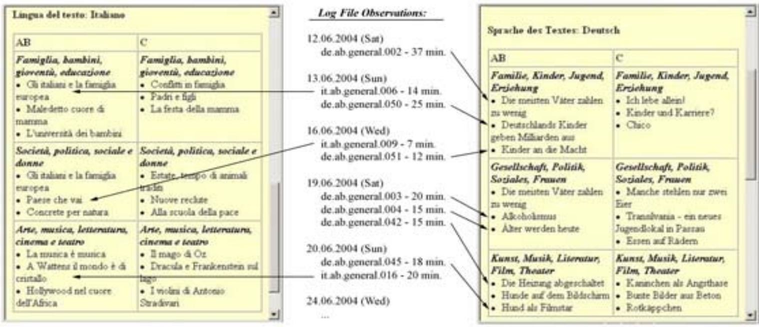


Figure 32: Example of consecutive browsing behaviour of a user

Behaviour (goal) changes with time: Some users reported changes in their own behaviour a short time before the exam date. For example a user at the beginning was using the system mainly during the week-ends and more often in the mornings (also this can be seen from the log files). He was reading texts in the language that is more difficult for him (Italian), as the goal was to learn new words. As the exam date was drawing nearer (the last 2 weeks before the exam) the user was using the system much more often – almost every day after work (workdays' evenings) and was reading mainly texts in the mother tongue (German), trying to answer the questions in the target language (Italian). The users that were not aiming at the exam do not report changes in their behaviour.

Importance of missing words: In our first prototype version we asked the user to grade the importance of every missing entry. Our initial idea was to try to distinguish a group of words that are critical for the understanding of the text and others that were not that important. On every miss users were given a form for grading the importance of the miss with tree-values scale of importance. Later we saw that this is quite useless, as (after the first access) every word that is requested is important for the study process.

The students that were preparing for the exam were grading the miss almost always with the highest grade. The ones that were not aiming at the exam were also giving a high value, and only in some rare cases were giving lower grades.

Different importance of different types of words: Again in the context of hoarding we examined the usage of different types of words – nouns, verbs, etc. We found out that about 50% of the requests are for nouns, followed by verbs – 30% (see Figure 33). However we discovered that, from the point of view of the hoarding, verbs are a critical point, especially for the pruning (excluding) phase. In our initial experiments we considered a word to be known to the user if he/she had the possibility to look at its entry from a text, but has decided not to revise it. Sometimes we considered a verb to be known to the learner from even several consecutive texts, but later on the same verb could be requested again. This happens because the verbs are linked to the entry based on infinitive form, so the user might be unfamiliar with a particular conjugation which is more rare or difficult.

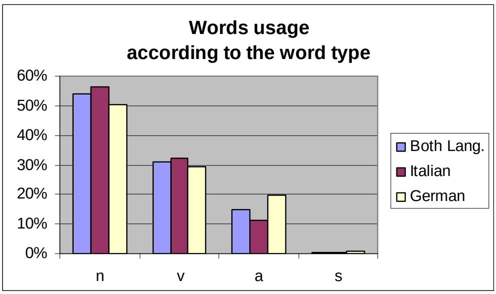


Figure 33: Words usage according to the word type

Usage of additional material and notes taking: Users that were preparing themselves for the exam of bilingualism were (almost always) using additionally a study book and a dictionary. Partially this is due to the fact that in the current version not all word entries of the texts are developed. Moreover these users were also taking paper notes. As we were not giving instructions on how the user could write and save the answers on the device and synchro-

nize it later, most of the users were not doing it, but later they mentioned that this option will be very useful. On the other hand some said that they study better if they take paper notes, so they would do it anyway. Users that were not preparing for the exam generally were not taking paper notes and were less using an additional dictionary – they were trying to guess the word meaning from the text context.

Target language: Another difference was observed between the behaviour of users that were preparing for the exam and the ones that were just studying the target language. As mentioned the texts are both in German and in Italian. For the bilingual exam the student should read a text in one language and answer to questions in the other language. This is done for both languages. Texts have two difficulty levels (AB and C). Users who were preparing for the exam concentrated on one difficulty level, namely the level for which they wanted to conduct the exam (see Figure 34).

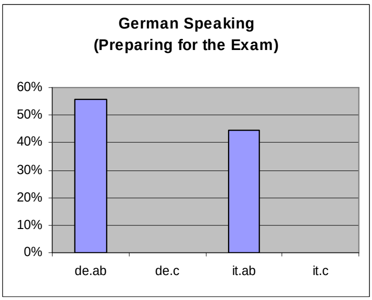


Figure 34: Typical pattern for a user preparing for the bilingualism exam

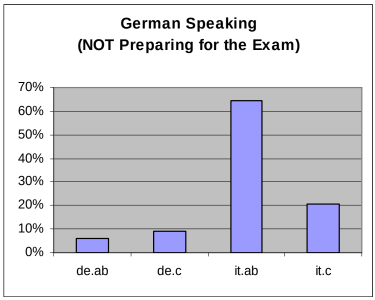


Figure 35: Typical pattern for a user not preparing for the bilingualism exam

Typically they were reading texts in both languages, concentrating slightly more on the texts in their native language, since in this case it is harder to compose correct answers (remember that students have to answer questions in the other language). Alternatively users that were not preparing for the exam were concentrating on texts in the target language (e.g. Italian for German speak-

ing user) and this without considering the difficulty (see Figure 35). Only driven by curiosity they also browse texts in their native language.

5.3.3 Hoarding with 'Critical Set'

In our first hoarding experiments we showed that the simple rule for hoarding which we used worked in the sense of decreasing the size of the hoard and thus increasing the hit_rate, but there are sometimes a large number of entries that are wrongly excluded/pruned. As a next step for improving the hoarding algorithm we decided to concentrate on the aim to minimize the miss_rate. As mentioned before every miss in the hoard might be critical for the users' understanding of the studied material and thus the low miss_rate is probably the most important factor for the hoarding process.

The addition of time measurements (shown on Figure 30) in the hoarding algorithm as a guarantee for real review of the material was a simple step that helped excluding some of the misses – the surrounded ones on Figure 29. However still lots of misses were appearing.

It was also mentioned that in ELDIT words are always linked to their infinitive form, thus that even different forms of the same word are requested by the same URL. For example all derivations of the word '*sentimento*', like '*sentimentale*' or '*sensazionale*' are requested and thus saved in the log files, by the link *it.n.sentimento.1.derivati.* Nevertheless in certain texts a word and its unusual form or conjugation might be very important for the understanding of the text. This means that certain words might be 'critical' for these texts, for users' understanding or for answering the comprehension questions. Such 'critical' words might be included into a 'Critical Set', which we will use for improving the hoarding performance.

Our supposition is that such words will appear very often in the requests, i.e. a large number of the users will review them. For example one can see on the Figure 36 below that the words '*sentimento*' and '*scaricare*' are requested by three out of four users

(note that these are the infinitives, while in the text a verb's conjugation and a specifically difficult form might be given, as in this case '*assentivano*' is a form of one of the fourteen derivations of '*sentimento*').

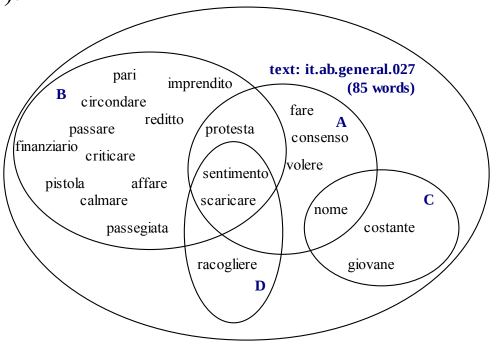


Figure 36: Overlapping in users' requests

We have also noticed that there are words, throughout all the tracking data (not only for a particular text), that appear very often. Examples are the verb '*essere*' and the noun '*nome*' that are requested an order of magnitude more than other words. Though their so frequent appearance in the logs probably has a very good pedagogical and linguistic explanation we are actually interested in the fact that the automatic discovery of such words is very simple and in the same time adding them to our, so called, 'critical set' might improve drastically the hoarding process.

We have performed an analysis on the frequency of use of the words in every text and created an ordered list of them according to the number of occurrences in the log files. The idea is to create a 'Critical Set' for every text, which will contain a number of the most requested words. Every time a text is prepared to be hoarded the words of its 'Critical Set' will be included into the hoarding set independently of the fact if it is in the user's knowledge-base and is prepared for pruning. In other words even if up to this moment the system believes the user knows some of these words they will be made available during the offline period.

An important thing to decide is how many words should be included into the 'Critical Set'. At the same time it is important to

keep an eye on the overhead that the 'Critical Set' brings to the hoard. By overhead we mean what fraction of the whole set of words is included into this addition to the hoard, i.e. how bigger the final hoarding set becomes because of the inclusion of the 'Critical Set'. In other words if we decide that 10% of all words, that are the most frequently used ones, will be included into the 'Critical Set' it will bring a (maximum of) 10% increase to the hoard. In the Figure 37 below we show the number of satisfied requests as a function of the hoard overhead.

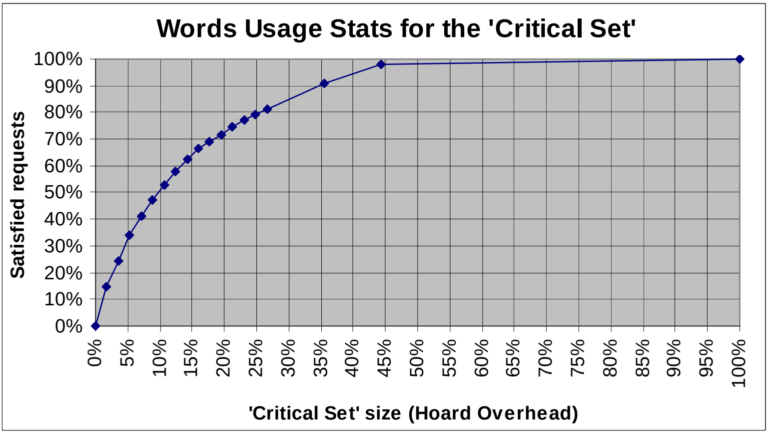


Figure 37: 'Critical Set': Average hoard overhead in respect to the satisfied requests

It is obvious that the bigger the 'Critical Set' is the bigger the number of satisfied requests will be, thus the smaller the miss_rate value will be. But on the other hand this will lead to increased size of the hoard and thus lower hit_rate. Nevertheless one can see that the improvement is steeper at the first few percents of overhead, because of the unequal distribution of the requests. On Figure 37 one can see that in Mobile ELDIT with only about 5% of the overhead in the hoard almost 35% of all requests will be satisfied and a 10% limit of the 'Critical Set' will lead to satisfying about 50% of the students' requests.

Though the initial idea for adding the 'Critical Set' was for increasing the accuracy in terms of decreased error_rate it might

be used also for increasing the speed of the hoard_size decrease. It is very possible (at least it turned to be the case for Mobile ELDIT) that part of the words in every text is never accessed. On Figure 37 above it is about 50%, but it is because of the small number of users we had during the current experimentations. Nevertheless we would expect to have a certain percentage of items that are never used even with big number of learners.

Figure 38 below shows how both the hoarding size and the error_rate will decrease with the help of the 'Critical set'. One can see that still the hoard size is much bigger than the real learner's usage. At the same time, though much less than in the first trial, still errors appear.

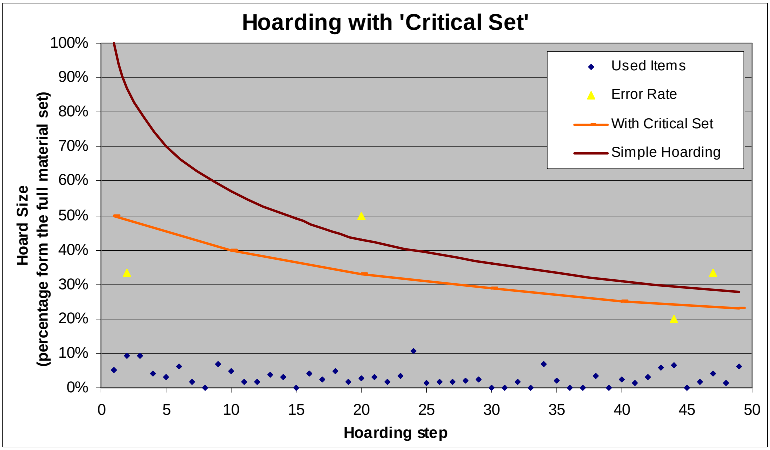


Figure 38: 'Critical Set': Hoard size and error rates

The first effect (the hoard does not become smaller than 20%) is due to the way we were doing pruning. In fact for this experiment we were excluding two things – first, as in the first experiment (previously described in 5.3.1), the items that were shown to the user but he/she decided not to use (e.g. what we consider the 'user knowledge' set contains); and second we were excluding the items (words of the current text) that were never used by other users. This percentage in the texts that we used was never bigger than 50%. We would expect that it will be even smaller if bigger number of users were using the system. However we could also

decide to add a threshold bigger than 0 for pruning, for example 5 or 10% (i.e. to prune rarely used items). This would make the hoard decrease even more, but would possibly increase the error_rate. Thus it is important to mention that this threshold for pruning is one of the parameters that should be carefully chosen in a real-world system.

The second effect, namely the continuing existence of hoarding misses, happens because the user actually requested an item that was never before requested by other users and thus was pruned. In our opinion this effect is mainly because of the small number of users that we had for the experiments. In a situation when tracking data from much more users will be available we would expect this to happen rarely.

In the cases when the device's available memory is still smaller than the predicted hoard after the pruning step we could use the usage percentage as a criteria for ordering the items for hoarding (step 4 of the general algorithm, described in Section 4). The prioritizing should be done after pruning the items, which belong to the user knowledge set. Nevertheless in some cases, when the percentage of usage for a certain word (LO in the general case) is very high the item might be considered to be included into the hoard, even if it is in he 'user_knowledge' set. These would be the cases when a particularly difficult word form (e.g. verb conjugation) is used. The thresholds of the percentages should be experimentally set.

5.3.4 Combined Hoarding

As discussed previously for speeding up the process of decreasing the hoarding size a possible strategy is to try to predict what learning objects (study material) is known to the user, instead of, as we did in our first experiment, to wait until the concrete portion of the material is shown to the learner. In other words after the first interaction of a learner with the system we should try to discover what the user knows, e.g. what objects should be put into his/her 'knowledge base' set. We might do this by finding similar (in their knowledge) users and if a certain user has shown that

knows certain word we can suppose that another user with similar knowledge will also know it. The two steps that have to be applied are:

a) to use some algorithms to discover automatically similarity between users;
b) to predict user behaviour based on known study patterns.

It is also important to mention that with higher number of participants we would expect great diversity in users' behaviours and in the sets of words they know. The large quantity of tracking data will lead to lower the performance of the hoarding algorithm and more specifically of the pruning, as done until now and described in the previous section. What is referred here is the fact that with increasing number of users we would expect that the number of words that were never requested will decrease on the account of those requested rarely (by few users). In other words when trying to apply the described in the previous section strategy for pruning we will have every time less items to prune. A useful thing to be done is, again, to group users by similarity and do the same statistic only based on very similar users.

We have tried to do automatic grouping of our learners based on different criteria and combinations of parameters. Our objective was to find if there are meaningful ways to do such grouping with the parameters extracted from the tracking data. The goal of this experiment was not only to see if the algorithm can automatically split the users, but also to see of there is some persistency in the clustering, based on different chunks of data (the separate, but consecutive texts, as they were presented to the users). What was important to know is if the grouping done based on part of the information (the part extracted from the first iteration(s) of the user with the system) preserves in time and could be used for our needs.

Automatic grouping of the users was performed, based on the words usage for 16 users over six texts. The data that was fed-in the clustering algorithm was in table form. For every text a table was created where rows represented the users and columns represented the words linked inside the text. The cell value was

set to 1 if the word has been requested by the user and to 0 if the user did not review it. In such a way the grouping of the users over one text was independent of the grouping for the other texts. We applied k-means clustering (details about the algorithm are available in [36]), and forced 2 clusters to be produced. The optimal number of clusters might be discovered automatically, however we preferred to force only two clusters to be created in order to be able to use the information of users' words usage in our hoarding algorithm. In Table 4 below we show the results of the grouping. The cluster to which each user was assigned is written in each cell. What is noticeable is that the classification is generally stable, i.e. the users are classified quite steadily in the same cluster. Note that half of the users (the dark grey-shaded ones shown in the first column) are classified always (i.e. for all the six texts) in the same cluster.

Table 4: Result of the automatic grouping of users based on the requested words

User	Text 1	Text 2	Text 3	Text 4	Text 5	Text 6
1	2	1	2	1	1	1
2	1	1	2	2	1	2
3	1	1	1	1	1	2
4	1	1	1	1	1	1
5	1	1	2	2	2	2
6	1	1	1	1	1	1
7	1	2	2	2	2	1
8	1	1	1	1	1	1
9	1	1	1	2	1	2
10	1	1	2	1	1	1
11	1	1	1	1	1	1
12	1	1	1	1	2	1
13	2	2	2	2	2	2
14	2	2	2	2	2	2
15	1	2	2	2	1	2
16	2	2	2	2	2	2

We can use the information extracted with the clustering algorithm for measuring the similarity between users. A possible approach is to calculate the User_similarity, as a count of occurrences in the same group throughout different texts. With the example data given above (forced two clusters) we receive the following similarity table (Table 5). The most similar ones are

marked with shade, that have been preserving their (maximum) values after the fifth and for sixth texts.

Table 5: Users' Similarity

	U_1	U_2	U_3	U_4	U_5	U_6	U_7	U_8	U_9	U_{10}	U_{11}	U_{12}	U_{13}	U_{14}	U_{15}	U_{16}
U_1	-	50%	50%	67%	33%	67%	33%	67%	33%	**83%**	67%	50%	33%	33%	33%	33%
U_2	50%	-	67%	50%	**83%**	50%	50%	50%	**83%**	67%	50%	33%	50%	50%	**83%**	50%
U_3	50%	67%	-	**83%**	50%	**83%**	17%	**83%**	**83%**	67%	**83%**	67%	17%	17%	50%	17%
U_4	67%	50%	83%	-	33%	**100%**	33%	**100%**	67%	83%	**100%**	83%	0%	0%	33%	0%
U_5	33%	**83%**	50%	33%	-	33%	67%	33%	67%	33%	33%	50%	67%	67%	67%	67%
U_6	67%	50%	83%	**100%**	33%	-	33%	**100%**	67%	83%	**100%**	83%	0%	0%	33%	0%
U_7	33%	50%	17%	33%	**67%**	33%	-	33%	33%	50%	33%	50%	**67%**	**67%**	**67%**	**67%**
U_8	67%	50%	83%	**100%**	33%	**100%**	33%	-	67%	83%	**100%**	83%	0%	0%	33%	0%
U_9	33%	**83%**	**83%**	67%	67%	67%	33%	67%	-	50%	67%	50%	33%	33%	67%	33%
U_{10}	**83%**	67%	67%	**83%**	33%	**83%**	50%	**83%**	50%	-	**83%**	67%	17%	17%	50%	17%
U_{11}	67%	50%	83%	**100%**	33%	**100%**	33%	**100%**	67%	83%	-	83%	0%	0%	33%	0%
U_{12}	50%	33%	67%	**83%**	50%	**83%**	50%	**83%**	50%	67%	**83%**	-	17%	17%	17%	17%
U_{13}	33%	50%	17%	0%	67%	0%	67%	0%	33%	17%	0%	17%	-	**100%**	67%	**100%**
U_{14}	33%	50%	17%	0%	67%	0%	67%	0%	33%	17%	0%	17%	**100%**	-	67%	**100%**
U_{15}	33%	**83%**	50%	33%	67%	33%	67%	33%	67%	50%	33%	17%	67%	67%	-	67%
U_{16}	33%	50%	17%	0%	67%	0%	67%	0%	33%	17%	0%	17%	**100%**	**100%**	67%	-

A similarity measure might be defined also directly based on the words used in every text (as the grouping is done). In other words similar will be users that have more cases of known/unknown words that are the same. In the most cases the similarity measured with the two methods overlaps well. On the table below (Table 6) we show an example with one of the users.

Table 6: Users' Similarity - comparison

	U_1	U_2	U_4	U_5	U_6	U_7	U_8	U_9	U_{10}	U_{11}	U_{12}	U_{13}	U_{14}	U_{15}	U_{16}
U_3 based on groups	50%	67%	**83%**	50%	**83%**	17%	**83%**	**83%**	67%	**83%**	67%	17%	17%	50%	17%
U_3 based on text2	79%	**88%**	**94%**	79%	**85%**	59%	**88%**	**85%**	71%	82%	76%	79%	74%	82%	62%

We have performed experiments on clustering the users based on other parameters, like the usage times, both for single words and

aggregated data for every text. As explained earlier (section 5.3.2) our users reported longer review times if their goal was to take the examination. Our supposition was that such study might help for prediction of students' goals, more specifically about the goal to take the bilingualism exam or not.

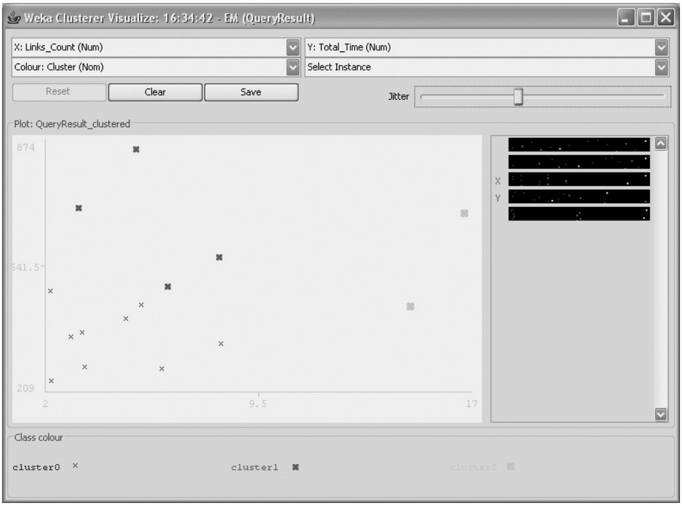


Figure 39: Clustering of users, based on requests number and spent time

However due to the small number of participants and in particular small number of user who aimed at the exam, we were unable to obtain meaningful data for the hoarding results. Still, clustering according to usage time, as the one shown on Figure 39 will certainly be useful as a step further after the separation based on concrete requested words.

An important question to answer for a real-word system would be "what should the number of clusters be and what does this number depend on?". In our experiments we used two different methods – 1) leave the algorithm automatically to discover the best number of clusters and 2) force the creation of to 2, 3, etc. number of clusters. It proved that in certain cases the automatic separation is not possible, again because of the small data set we experimented with. On the other hand in Figure 39 we show re-

sults when the clustering algorithm automatically discovered three clusters. Still, in most of our further experiments we forced two clusters to be produced.

As discussed earlier our current goal is to predict the user behaviour and needs. Based on the clustering shown in Table 4 we experimented on using prediction algorithms. The data was split into training (60%) and testing set (30%). We used the data, collected for texts 1 to 5 and the clustering as shown in the Table 4 for predicting the grouping for the last text.

Table 7: k-Nearest Neighbours Prediction (value of k)

Value of k	Training RMS Error	Validation RMS Error	
1	0.273861279	0.433012702	
2	0.273861279	0.433012702	
3	0.273861279	0.348792827	<--- Best k
4	0.273861279	0.387887144	
5	0.273861279	0.405825766	
6	0.273861279	0.371410282	

The algorithm (details about the algorithm can be found in [36]) analyses what is the best value of k, i.e. the number of neighbours to be compared during the prediction (see Table 7).

Table 8: k-Nearest Neighbours Prediction (correctness)

Row Id.	Predicted Value	Actual Value	Residual	
2	1.75	2	0.25	correct
7	1.777778	1	-0.777778	wrong
8	1.25	1	-0.25	correct
13	2	2	0	correct
14	2	2	0	correct
16	2	2	0	correct

The prediction results are shown on Table 8. Experiments with different random separation of the users into training and testing set gave error of 17%-33% (i.e. 1 or 2 out of 6 wrong predictions). The prediction based on 3 clusters and also manually

choosing the text over which the prediction to be done gave the same precision.

5.3.5 Association Rules

In section 4.7 we discussed the importance of prioritizing the LO that are selected for hoarding. A possible technique to be used is the utilization of automatically discovered associations as rules for increasing or decreasing the priority for the LO of the 'Candidate' set. For example the following rules (Table 9) are discovered over all users' requests on one of the examined texts.

Table 9: Association Rules (all users, Text 4)

	Conf. %	Antecedent (a)	Consequent (c)	Supp. (a)	Supp. (c)	Supp. (a U c)
1	100	it.n.ambiente.1.lemma=>	it.n.camicia.1.derivati	3	6	3
2	100	it.v.mollare.1.lemma, it.v.stirare.1.lemma=>	it.n.gancio.1.derivati	3	10	3
3	100	it.v.rendere.1.lemma=>	it.n.gancio.1.derivati	3	10	3
4	100	it.v.stirare.1.lemma=>	it.n.gancio.1.derivati	4	10	4

As one can see from the table above even in a quite small tracking data set quite strong rules can be found. In the example given here we required the confidence to be 100% (i.e. should be true for every 'antecedent') and support > 18% (i.e. three or four out of 16 users requested the words (a) and in all cases a request also of (c) was made).

Table 10: Association Rules (cluster 2 users, Text 4)

	Conf. %	Antecedent (a)	Consequent (c)	Supp. (a)	Supp. (c)	Supp. (a U c)
1	100	it.n.ambiente.1.lemma=>	it.n.camicia.1.derivati	3	4	3
2	100	it.v.mollare.1.lemma=>	it.n.gancio.1.derivati	4	7	4
3	100	it.v.mollare.1.lemma, it.v.stirare.1.lemma=>	it.n.gancio.1.derivati	3	7	3
4	100	it.v.rendere.1.lemma=>	it.n.gancio.1.derivati	3	7	3
5	100	it.v.stirare.1.lemma=>	it.n.gancio.1.derivati	4	7	4

When association rules are acquired after clustering the users, as described in the previous section, we can find even more meaningful or stronger rules. Examples are shown in Table 10 - in this case more rules are found and the support of the extracted rules is

35%-50%. With the previous settings in one of the two clusters only 2 rules are found, while in the other cluster - more than 100 rules.

The clustering described so far and association rules discovering should serve for further decreasing the hoarding set. It would be done by prioritizing the LO and setting certain limits for what to include/exclude. It leads to the situation shown in Figure 40. The green dotted line shows the presumable size of the hoarding set if all mentioned techniques are used. How high/low the line will be, depends on the parameters (limits) set for the pruning.

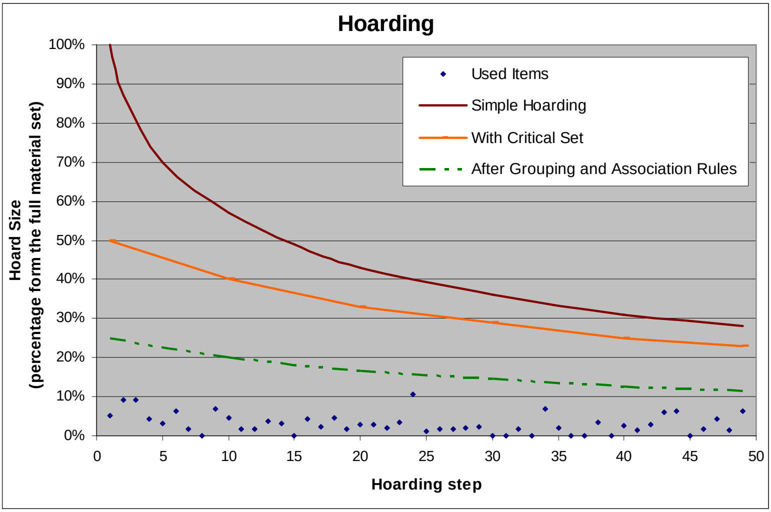


Figure 40: Hoarding (presumable) with 'Critical Set' and after LO prioritizing

Note that the 'Critical Set' statistics might be done after clustering and classifying the users into groups. For doing such experiment and extracting meaningful results though we would need more tracking data than available currently.

5.4. Other outcomes from the mobile learning system

Some other outcomes, not related to the hoarding problem, were obtained by observing the participants and from interviews and

questionnaires with the users of Mobile ELDIT. There are both positive and negative outcomes. Most of the problems we found up to now are of a formal nature and are not directly related to our research work. Therefore the positive outcomes reported at the beginning of this section are much more important for us and encourage us in our approach. Nevertheless we find it important to report them as they would be common for all research in m-learning domain and might help for the future development of mobile learning applications.

5.4.1 Positive Outcomes

- ✔ The users of Mobile ELDIT found the system very easy to use. Even those that have never used similar devices started using the system almost without problems after a 10 minutes introduction. The users liked the browser interface a lot, as they felt familiar with this way of interaction.
- ✔ One thing that almost all users mention they liked in having a mobile learning system is the availability – because of the fact that the device is light and small one can put it in his/her pocket or purse and have it with him/her all the time.
- ✔ Some users of Mobile ELDIT were familiar with ELDIT (the online desktop system). They reported, after getting used with the mobile system, to have started to use the two systems in different ways. As the mobile one was more comfortable for using it in any moment they started using it for systematic studying, especially on the road. However often the mobile system was utilised also at home even when a PC was available. On the other hand they started to utilize the online system more often for searching and controlling the meaning of the arbitrary words, mainly at work.
- ✔ The users liked a lot the freedom that the mobile device gives them. Some of them often used the system in the train while travelling, others at home or in the office. To the question "*Is there a place where you preferred using the system? Why?*" one user responded "*On the coach. Because it is comfortable*

☺". Another user answered "*None. As I could (and did) use it in any environment.*"

- Two of the persons, who used a mobile device as an additional tool for the exam preparation have passed the exam and said that the system has helped them a lot. Though this is not a real measurement for an increased learning effectiveness it is a hint for the users' perception of benefit which such a system brings into their learning process. Our interviews have also shown that missing portions of the learning material are perceived very negatively. In this context the existence of an efficient hoarding subsystem plays an indispensable role for the overall measurement for positive effectiveness of the system.

5.4.2 Problems Found

- As it was mentioned before wireless and mobile devices' market is very dynamic. Fast changes happen also in the software field for mobile devices – few operating systems are available that are incompatible between each other but are often incompatible also within versions. This fact triggers research in device independence technologies, but often parts of the developed system should be written specifically for a given platform. A possible solution that we tried to explore is the usage of java technology for overcoming the problem of "developing the same thing twice". Our experience shows that in this early stage there is no even Java Virtual Machine (JVM) with equal behaviour for the different platforms. Even worse – using the same JVM our system was not equally stable across different OS versions. Our expectation though is that this problem (inequality of JVMs and other standardization issues) will soon diminish and hopefully disappear. Until then careful planning should be done on what hardware platform to use and what should be the software development solution that should satisfy the need of a given project.
- As our main experiments were carried out on Windows-based devices we gathered some experience on the specific prob-

lems that appear with them. A significant problem is that the battery of Windows based devices discharges quite fast. When a device is frequently used it discharges in 1-2 days, but the main problem comes from the fact that even when not used the battery discharges in about a week time. The discharged device “forgets” the software installed by the user/administrator and all user’s data. This leads to the necessity to do backups of all important data on an external memory quite often. It is also very inconvenient and even irritating as all the programs that were installed should be re-installed.

- ✔ Another particularity of the Windows CE based PDA devices is that once a program is run it remains in the device memory until specifically closed from special menu command. The misunderstanding comes as the programs generally are not closed when the x button in the upper right corner is pressed, while the users think it will. As lots of users were not previously familiar with such devices they were often clicking and starting by chance and unwanted different software. Once realising the mistake they were closing it as they would in a desktop PC by clicking the x button. In this manner very often lots of programs remain open and occupy device’s memory, making the rest work much slower and even making programs crash.
- ✔ As our experiment was connected with offline delivery of material we introduced a client-side proxy that should simulate Internet access even in offline periods. The problem that appeared was that Internet Explorer (the browser available on windows based mobile devices) does not send requests to the local proxy if it does not find an Internet connection by itself. This made it necessary to use another web browser. Unfortunately all other browsers at that moment were commercial products. Very recently a free Mozilla browser for Pocket PC has been developed. However at present its early version still does not fit to our requirements.
- ✔ Problems were found also considering the presentation in the browser we have used. Special German and Italian letters are

not always presented correctly, thus the browser should be chosen carefully in advance.

- ✔ The first version of our prototype works with a large number of small files (several thousands). We have observed that the file transfer from the desktop PC to the mobile device is a very slow operation, when lots of files are being copied (e.g. about 5-10 times slower for transferring small files, comparing with transferring one big file). This means that packaging is strongly needed. The process of deleting big quantity of small files is also very slow.
- ✔ The use of packaging helps solving the above mentioned problem (see Figure 41) but also brings additional load to the system. First of all the system needs more time to load the cached content if it is zipped (see our measured times on Figure 42, base on an Acer n-10 device).

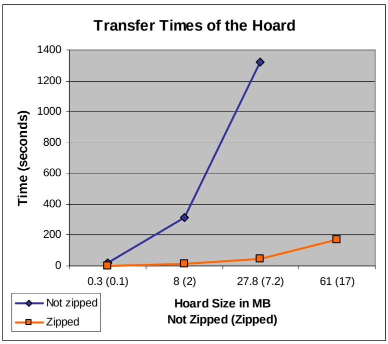


Figure 41: Transfer between desktop PC and PDA device

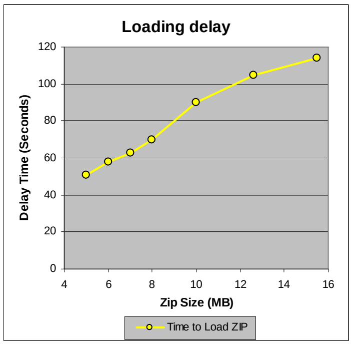


Figure 42: Load Times for Zipped packages

We should point out that on a system that does not use packaging the load time is practically zero, while one can see on the figure above that the load time for even quite small package size are quite high. Nevertheless the interviews with our users showed that the load time is not as disturbing as the reply delays of the proxy. In other words the users would not mind to wait for about a minute or two while the system

loads, as this happens once in a while, as long as the requested content is not delayed too much.

On Figure 43 we show that the introduction of zipping for our system has a positive effect on the proxy response time for smaller package sizes (up to 8MB), while for bigger packages the reply time increases. We should mention that it depends strongly on the percentage of misses, because of the particularity of a slow reply when a miss is encountered. For the figure we used 20% of miss rate, which would probably be too high percentage in a real hoarding system, and was slightly above the average in the experiments described previously.

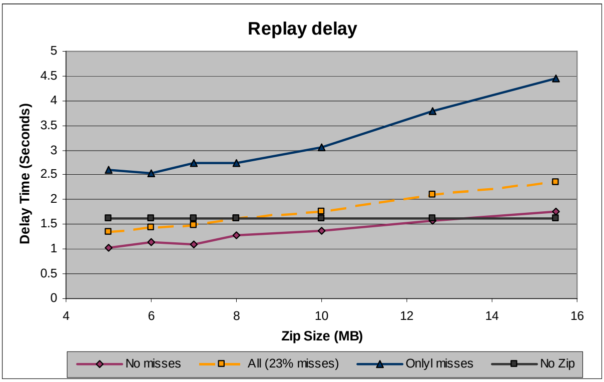


Figure 43: Response Time depending on the package size

- Though this is not really a problem, but rather a fact that should be taken into consideration, we would like to share another observation which we found important. Generally users' expectations for the PDA system functionalities and speed of work are much higher than the one available nowadays. Except from the people that had used PDA devices before, all our users were complaining that they expect the device to behave more 'similar' to the desktop PC.
- Our experiments were done with PDA devices that were especially bought for this purpose, as none of the users that were eager to participate owned one. However we discovered

that generally (with small exceptions) they were not willingly exploring any additional functionalities that the device and its pre-installed software were offering. Unless we have specifically suggested them to use certain functionality (for example taking notes on the device) they were using only the Mobile ELDIT system. The probable explanation of this fact and a similar example was found in [101] – the user motivation to waste time into exploration of the new device decreases if the user is not owner of the device.

Chapter 6

6. Related Work

As can be seen in the state-of-the-art section, mobile learning incorporates a wide variety of applications that use different technological approaches. What is missing in most of the proposed architectures and systems is that they consider either only online access to the content and services or they are designed especially for small content data that fits all into the device memory (example: the http://www.hotlavasoftware.com mobile learning courses). This is valid not only for mobile learning, but for mobile domain in general (see for example [16]). The point to consider is that in some scenarios (like the learning one) the content that is to be delivered can be quite large. Only some transcoding proxies take care also for caching web pages for offline usage (e.g. AvantGo). We think that delivering content for offline usage is an important issue as still mobile devices are often disconnected because of the lack of network access in certain places or because of the high prices in most of the cases, thus our intention is to support both online and offline access to data.

A problem similar to the one we face (off-line access to data) is treated in the offline browsing of web-content. A review of the available offline browser utilities (like www.avantgo.com, www.httrack.com, www.webstripper.net, etc.) shows that generally during the online periods the user selects sites that should be uploaded for later off-line usage and entire sites are dumped to the local storage or the user specifies the depth of the links to be cached. In situations where mobile devices are considered the memory limitations make such an approach often unfeasible, as the data set might be bigger than the available space.

The caching problem has been studied in the general case for the Internet. Wang [109] presents a survey of the state-of-the-art techniques and elements of Web caching systems. These tech-

niques include Prediction-by-Partial-Matching, analyses of users' access patterns provided by the servers, prediction of the user's future Web accesses by analysing his or her past Web accesses, etc. Although some of these techniques are useful for predicting the content needed also in m-learning domain still they aim at a different goal – reduction of bandwidth consumption, of access latency, server workload and etc. They explore the case of the Web where the search space is much bigger, the users are numerous and have different interests thus the prediction accuracy is quite low comparing to what is needed in our scenario, but could be compensated by the fact that the Internet connection is permanent.

The idea of hoarding for disconnected devices in distributed file systems has been first described in [52], though in contrast with us they do not consider mobile devices in the sense of PDAs, but rather they consider laptop computers. They propose the Coda File System to explore the usage of caching of data not for improving performance but for increasing the availability. They propose architecture for hoarding and for keeping the coherence of the utilized files. The initial system was based on client-server architecture which tracks the local file modifications and saves a 'Client Modification Log'. The project has lately evolved into UbiData project [38] and the direction taken is in double-middleware architecture for ubiquitous data (file) access. They introduce incremental hoarding, where the idea is to use a version control system to maintain object differences and also study the automatic data selection problem. A metadata server is included to store the 'users' mobile profile' which keeps a list of user files that are considered 'interesting'. They define a "hybrid priority" metric for choosing the hoarding set of files. The "hybrid priority" is calculated by taking into account the recency of use, the frequency of access and the active periods of the file usage. The algorithm also considers upper space limit of memory. The reported effectiveness of their filtering algorithm is more than 84% [115].

Facing the hoarding problem for mobile computing disconnected operation an interesting solution has been proposed in SEER [57]. The authors were also inspired by the work on Coda system but go in different direction. They defined a new measure, "semantic distance", between individual files by observing the user activities and propose an algorithm for automatic hoarding of projects for mobile computers. With "semantic distance" the authors try to quantify the user's intuition about the relationship between files in the same project. For this different measuring criteria are used – "temporal semantic distance", "sequence-based semantic distance", "lifetime semantic distance", directory membership, filename conventions and hot links. These criteria are combined to assign weights to documents and take decisions for hoarding them in an automatic way (automatic periodic hoarding). The approach met some unpredictable behaviour in the real-world system, which appeared because of the way the operating systems and some often used programs work (like the "find" operation under Unix). Recent experimentations with the same system [58] showed surprising finding – the complex clustering methods that are used in the system work in most of the cases worse then a LRU (least recently used) algorithm enhanced with some heuristics.

Another system for experimenting with the hoarding problem is the WebScrooge Hoarding Agent [14] which deals with the Web browsing. Their strategy includes user-defined priorities, recency of document use and predicting of access patterns in order to provide reasonable Web availability during periods of low or intermittent connectivity. The user requests are captured by a local proxy, which first searches in the local cache for the requested page and if the entry is not found it is retrieved from the server and meanwhile stores it locally. In their system the hoarding agent is called 'profiler' – a module that is responsible for periodically calculating the priorities of the cache entries and keeping the cache in a state of equilibrium. The tests were done with hoard set size of about 25% of the full URLs set. Though on the first sight this system seems very similar to our work it has major

differences. First of all the hoard updates of this system were in terms of seconds – 10 to 240. This means that disconnection period they suppose, if exist, are very short. Their experiments show also better results with frequent hoard updates (about 30 seconds). They get about 31% better performance in the sense of hit rate, comparing to LRU algorithm. As we discussed earlier in our case the LRU is practically useless, as the user will rarely review over and over the same study material.

According to our knowledge, on the scene of learning and related technologies hoarding has been hardly explored until this current work. In the rare cases when 'offline' is considered in conjunction with e-learning (like Backpack / Mobilizer for Blackboard, details available at http://www.syberworks.com) or mobile learning (see few alternative approaches discussed at http://learning.ericsson.net/mlearning2/project_one/presentation_ipaq.html) the content is supposed to be manually selected for downloading or is fully downloaded by the system without any consideration of the available space. The only profound and more formal study on the possible ways to treat the problem of disconnection in a mobile learning scenario was found in [44] and [27]. They propose two different architectural models, but their main concern is to track the user activities and synchronize automatically the learner's learning progress records. Both architectures do not consider the problem of what material to be pre-fetched. Furthermore we are not aware of continuation and practical development of a real system based on these architectures.

Chapter 7

7. Conclusions and Future Work

This thesis work, though aiming from the very beginning at solving a very concrete problem, namely the hoarding of content for mobile learning, in its depth appears to trigger a wide variety of research and development issues. Different parts of this multidisciplinary process of design and implementation of a concrete mobile learning application are discussed thoroughly.

We have started with a deep analysis of the mobile learning field and with the lessons learned previously in different projects. We gathered the experiences of the others in a very early stage of the m-learning domain and we have included them into guidelines for developing a successful mobile learning application. We reported these guidelines and used them in our further work. We then checked their applicability in our own environment, performing a survey on Italian and Bulgarian university students in order to verify the students' expectations and readiness to use mobile devices for certain learning activities. Interesting observations and find-outs also stimulated our decisions.

We have also deeply analysed the similarities and differences between current e-learning platforms and the functionalities they offer to the users and the services that should be accessible in mobile learning. Based on this we proposed a general mobile learning architecture which should be able to transform all possible functionalities from the e-learning platform and to add the new functionalities that come with the introduction of the mobile device. We argued that such a general mobile LMS should sit on top of eLMS and should have three main modules – one responsible for the discovery of context, one for mobile content management and adaptation and one for packaging and synchronization of the content for supporting offline delivery of learning material. With our implementation we show the viability of our arguments.

We have successfully designed and implemented a real-world mobile learning system, called Mobile ELDIT. Behind it sits an innovative language learning e-learning system, called ELDIT. Mobile ELDIT helped us also in gathering good practical experience from the work with real m-learning users. Based on the users' feedback we concluded once again that hoarding is very important and should be considered in developing m-learning platforms. Users' suggestions and advices also helped in understanding real students' needs for further system improvements.

Considering hoarding we have outlined the general solution, i.e. provided a theoretical plan for action with possible techniques to be used. We discussed step by step in details the proposed strategy, leaving it abstract enough to be general and applicable to different mobile learning systems. We point into some particularities of the mobile scenario that would influence on hoarding, like showing the importance of a new definition of user session for this scenario and the utilization of the measurements over it in hoarding. We compared different approaches (measures) for presenting the successfulness of the hoarding and discussed their pros and cons. This theoretical approach gives the basis of later providing a customized solution for a concrete system, leaving possibilities for future comparisons with other results.

Talking about practical results we have acquired and presented a number of positive results over Mobile ELDIT that show the correctness of the theoretical deductions.

It should be mentioned that though lots of work was done considering hoarding in mobile learning context, we are still far away for having an optimal general solution. One of the biggest problems in the experimentation phase appeared to be the need of big quantity of tracking data which to be fed-in the automatic knowledge extraction algorithms. As the m-learning field is so new there is no such data available in advance and gathering it requires time.

Lots of interesting issues that could not be researched because of time and other constraints appeared and would be nice to be explored in the future. Here I would like to list some ideas for

improvement of the currently proposed approaches and techniques, both for hoarding and for the prototype Mobile ELDIT system. Some general ideas for interesting research directions related to supporting offline access to learning materials and to mobile learning in general to which we come across during the thesis are also included.

7.1. Hoarding Improvements

Optimization of the hoarding process probably can be done in different directions. During the current thesis we did not get to the point of measuring the optimality of work of the algorithm, rather the goal was to prove the correctness of the ideas and strategies for creating the candidate set and for pruning. Throughout we tried to keep the steps as separate as possible, in order to have a clear idea of the processes and the successfulness or the faults on every step. On the other hand the concrete algorithm should be optimized and one idea for this is to try to optimize it by combining the steps of generating the 'candidate set' and pruning it into a single step, i.e. instead of first adding all connected to level *n* items of level *n+1* to the 'candidate set' and later pruning what is not needed it is possible when an item is selected for including to apply at the same time the pruning rules ad decide on the fly. However our work was mainly on testing possible techniques and we were targeting the improvements in terms of hoarding accuracy, rather than optimal implementation. Once the needed by the system accuracy is fulfilled many other further optimization of algorithm speed could be taken into consideration. It should be mentioned however that most time-consuming processes for the hoarding system might be done during users' offline periods.

Usage Patterns Observations

The hoarding process includes various steps, one of which is the prediction of the user's starting point and most probable path he/she will follow during the next learning session. During the work described here we observed that users generally followed very consecutive path, i.e. when given a list of texts the users

were reading them one after the other as they appear in the list, rarely skipping some of the texts and even more rarely going back to one that was skipped. However we didn't do more formal and deep automatic analysis on usage and access patterns because of the small quantity of tracking data we managed to collect. In our experiments we used the assumption that the student will have consecutive access pattern and we were concentrating on the other hoarding steps. In our opinion this is a weak point in our experimentation phase, as it is probable that in other systems that contain different type of learning material or data with different structure the research on access patterns will be crucial and should be thoroughly considered.

Larger Scale Experimentations

Results shown in the current manuscript are based on small scale experiments. It is clear that hoarding requires analyzing of user behaviour and acquired knowledge. Certainty for the correctness of the deductions depends strongly on the quantity of data that was analyzed. A logical step would be to check the correctness of the deductions in a larger scale. In this context especially interesting will be also to confront users' behaviour during the usage of a desktop and a mobile version of the ELDIT learning platform.

In this direction we have started a collaboration with Istituto Svizzero di Pedagogia per la Formazione Professionale (ISPFP) and the system will be used in real classroom environment with pupils. The collected tracking data will be further used for analysing the users for similarity and differences in the study styles and habits. Particularly interesting will be to see if there is an automatic way to distinguish the self motivated learners that we had until now from the teacher-guided pupils and how we can use grouping based on this to further improve hoarding.

Hoarding with Different Learning Materials: Multimedia

During this thesis the experimentations were made with the previously described Mobile ELDIT system. The learning material of ELDIT is a low-granulated – split into small chunks and so we

were experimenting with big number of items in the hoarding set. The learning material was text based so the LOs we were working with were of a small size. On the other hand we see clearly that often the materials held in e-learning systems are much bigger than the chunks we experimented with. Though we did out mining always in an abstract way which should permit the deductions to be applied to data with different properties it is possible to discover divergence.

It is well known that the use of multimedia is one of the main pedagogical advantages in the use of digital technologies in education. As mentioned in our practically developed mobile learning system we used only text representations, though for the hoarding we treated the material parts independently from the media. An important and interesting issue is to include also different multimedia elements in such a system. The main obstacle for such experiments in the current work was that preparing of multimedia learning materials is quite time consuming task and requires special artistic and/or pedagogical skills. Nevertheless different multimedia (pictures and sounds) is partially presented in the online ELDIT and its quantity is continuously growing. It will be interesting to see up to what extend the existing multimedia materials could be presented to mobile users. Of course important and motivating question to research is if adding different media will influence on the hoarding. In such case we will have to add also strong rules considering material size. Possible solutions might include alternative ways to present the same materials and other issues, widely discussed whenever research on personalization is performed.

It should be noted though that the addition of multimedia, if not especially designed and annotated for our purposes, might add additional technical problems, discussed also in [14], like the one of discovering embedded objects.

Pedagogical Issues

This thesis has in most parts a technical orientation. This led to the fact that one of the most interesting for the mobile learning

community direction was left outside the scope of the current work. It is the connection of the hoarding and its solutions to different pedagogical approaches and theories.

One example can be given with the idea to improve the study outcomes by combining hoarding with personalization. In the current work depending on the experimentation phases we either tried not to limit the browsing preferences of the users in any way or we were strongly limiting the possible actions. In the first case we were trying to predict and satisfy every user's request, leaving all possible links available and considering a 'hoarding miss' a negative measure for our system. On the other hand in certain cases it might be better from the pedagogical point of view to just not give the user the opportunity to reach to the point where a 'hoarding miss' will appear. For example the system should never show to a beginning user the information/learning material that is commonly for expert. In our system we were mainly leaving those judgements to the user itself. For checking the real outcomes of the learning process, not in terms of hoarding, more consideration should be paid on examining the acquired knowledge and comparing it with the learner's knowledge at the beginning of the mobile system usage, based on feedback, tests, quizzes and etc.

Some sources show (see section 6.7 of [73]) that about 95% of all the lexis in a text should be known to the learner in order to have good comprehension. Facts like this one can help hoarding, but we were not able to reach this point in the current work.

Another example is to add knowledge about the learning styles, strategies and sequences in order to help the hoarding prediction. For example as subject of our prototype was language learning one can study different theories of language learning and find out pedagogical rules to be used in hoarding. In [56] for instance is stated that there is a "natural order" in the acquisition of grammatical structures, regardless of the first language of a speaker.

Cooperative Hoarding within Ad-Hock Networks

Ad-hoc networks have been frequently discussed recently as a research issue. The idea to connect devices between themselves and using each other's services or resources is not new. For different learning scenarios we can easily imagine students with the same study classes being also physically close to each other. Generally, students that follow the same subjects will need similar, often overlapping learning materials. Base on this assumption (the physical closeness of students that might need similar materials) it would be interesting to experiment with collaborative hoarding in ad-hock networks. The ideas for two possible approaches are sketched in [60], though not considering the learning context. Discussed approaches though assume always that the hoarding engine will know in advance which are the devices that will form the ad-hoc network and use this information to fill-in the caches. On the other hand another possible approach would be just to use these networks to try to satisfy the hoarding misses.

7.2. Mobile ELDIT Improvements

Include simple dictionary: As described, the learning content of ELDIT is very elaborate and continuously growing. For every word in ELDIT are provided explanations and translation, a number of examples, idiomatic expressions, derivations, etc., grouped by concrete meaning. Yet in Mobile ELDIT only a portion is loaded for offline usage due to memory limitations. The main goal of this thesis was to research on the possible techniques to solve the hoarding problem, i.e. to satisfy all user requests. However in certain cases the user might like to access an arbitrary word, not following the links that we have provided from the texts or other words. The student might want to check the spelling of a synonym or to see the meaning of a word which he/she hears while on the street. In the current version of Mobile ELDIT such an arbitrary search is not provided as a functionality. However a possible and welcome solution will be the addition of a simpler dictionary, the entries of which can be shown to the user also in

the cases of hoarding miss. Such a basic dictionary might provide only translation of those words available in ELDIT.

Add multimedia material: We mentioned before that ELDIT content is continuously growing. This is true for enrichment of the dictionary with words, meanings, examples, etc. and also for adding different multimedia material. While in ELDIT most of the content is still in text form, Mobile ELDIT in its current version contains only text. In this context it is a necessary next step for improving the existing system to include also adaptation and transcoding of the multimedia content for the mobile users. At present the ELDIT provides certain explanations and examples in picture form and pronunciations as sound. However video formats should be also anticipated and support should be provided in Mobile ELDIT.

Add collaboration functionality: Mobile ELDIT is a limited version of an online language learning system. One part that we did not include was the collaboration between the learners. The so called 'tandem' module of ELDIT allows users with different mother tongues (Italian and German) to collaborate by playing the role of the teacher for the other person in a couple. This means that an Italian native speaking person will check the answers to the comprehension questions written in Italian by a German native speaking person. This very useful functionality was also requested by some of the Mobile ELDIT users. A possible improvement would be to connect the mobile system to the 'tandem' module of ELDIT and to research of the added value. It would be interesting also to experiment to 'mix' the mobile and desktop users.

7.3. Other Research Issues

Automatic Extraction of User Preferences

An interesting further direction of current work would be to analyse if and how possible is to extract automatically user preferences in similar manner, as extracting information about user be-

haviour and knowledge. For doing this it will be necessary to adapt the system so that the tracking data that is collected should be different, i.e. more extended.

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b) Mobile Web Initiative *http://www.w3.org/Mobile/*
c) XML *http://www.w3.org/XML/*
d) Style Activity (CSS, XHTML, SVG, SMIL, XSL and etc.) *http://www.w3.org/Style/*
e) Composite Capabilities/Preference Profiles (CC/PP) *www.w3.org/Mobile/CCPP/*

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Appendix A

During the thesis manuscript we gave a detailed explanation of different aspects of Mobile ELDIT system, but we concentrated on the technical perspective. Here we would present the system from the point of view of the user. A demo version of Mobile ELDIT was published online (for free download) in the beginning of 2005 and here is how the user gets introduction and instructions about usage and possible problems.

Mobile ELDIT User Manual

Index

GENERAL INFORMATION ABOUT MOBILE ELDIT

Mobile ELDIT (or M-ELDIT) is a system for studying German and/or Italian languages with PDA devices. It allows offline access from windows-based PDAs to the learning materials of ELDIT (http://www.eurac.edu/ELDIT) – an adaptable language learning platform.

The main design goal in the development of M-ELDIT was to be used as an additional tool for the preparation for the exams in bilingualism in the South Tyrol region. Though Mobile ELDIT targets mainly the users preparing for the mentioned exam it can be also used by people interested in practicing German and/or Italian languages.

M-ELDIT is a limited mobile version of the ELDIT system. It allows access to the texts and associated words in both German and Italian languages. All texts are divided into two difficulty levels and are split into thematic groups.

The users might browse through a number of texts and connected words that are previously packaged and saved in the cache of the PDA. In contrast to ELDIT it does not contain all arbitrary searched by the user word, but only the ones pre-fetched in the device local memory. As the system is under development the number of misses (the items that the user wants to see, but are not available) might appear. Mobile ELDIT works offline, utilizing a caching proxy, called *FoxyProxy*, thus does not require Internet connection. The proxy provides access to texts and words entries, leaving to the user impression of working online. It also collects in few log files information about the browsing paths of the users and times spent on particular pages. Regular backups of these log files are done on the external memory, if such exists. The system should be utilized through a special browser, called NetFront3, which should be installed on the device (see Instructions section further on).

PRE-REQUIREMENTS

There are practically no pre-requirements for using Mobile ELDIT. Basic skills on web browsing and PDA usage are enough.

- **What mobile devices could be used to utilize M-ELDIT?**

  The system is tested ONLY on few PocketPC devices – Acer n10, iPAQ 3800 and iPAQ 1940. Theoretically, the system usage is limited to devices for which the ewe virtual machine and NetFront browser are provided. To this date these are all Pocket PC, Pocket PC 2002 and Pocket PC 2003 devices. Please let me know if you try it on other than earlier mentioned mobile devices models so I can update the information here.

HOW DOES MOBILE ELDIT WORK?

Start the NetFront browser by clicking on its icon in the Start Menu / Programs or in the recent programs:

Automatically a page with the list of texts that are currently available is displayed on the screen, as shown on Figure 1. This list contains in table form the names of the texts. For the Demo package the texts are in both languages, German (on top) and Italian (following the German texts), and both difficulty levels (AB – advanced on the left and C – intermediate on the right).

Clicking on a text name will lead the user to a page similar to the one shown on Figure 2. In the upper left corner there is a link which will lead to the list of texts, though the user can always use the back button of the browser (the blue arrow next to the Tools menu on the figures).

Fig. 1: List of available texts

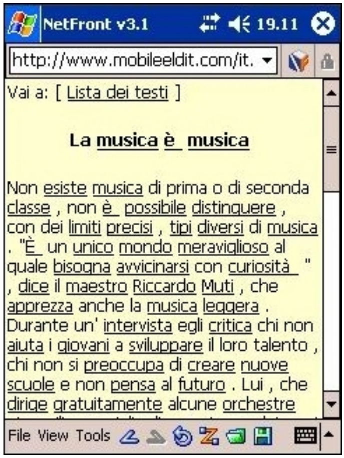


Fig. 2: Sample Text

The underlined words in the text are clickable and when pressed will generally lead the user to the basic word entry, which contains explanation of the word meaning, the translation to the other language and one or more examples of the word usage. Links to additional information are also provided at the beginning of the word-entry page, as shown on Figure 3.

Fig. 3: Sample word entry (Sense 1)

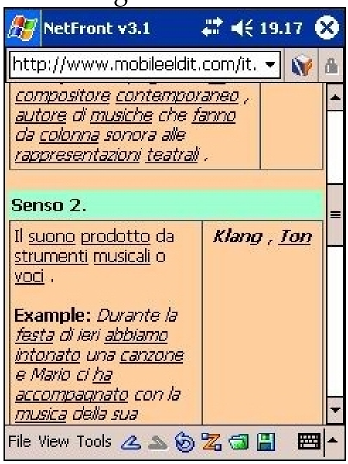


Fig. 4: Sample word entry (Sense 2)

In many cases the chosen word has more than one meaning (example shown on Figure 3 and Figure 4 – two meanings of the word '*musica*'). In such case all the meanings are provided one after the other, starting with the most common one and giving the above mentioned information for every meaning. It is possible that the word link provided from a text leads directly to the concrete sense, which is used in the context of the text and is not the first one in the list. If the word used in the text is a derivation form a certain words it is possible that the link leads directly to a screen like the one shown on Figure 6.

In the word entry page lots of words are also clickable and connected to the basic word entry to the chosen word.

Fig. 5: Sample word entry (Full - Collocations)

Fig. 6: Sample word entry (Derivations)

As mentioned at the beginning of the word entry page links might be provided to additional information. On the Figure 5 one can see part of the full entry of the word '*musica*' which contains also the usage combinations of the word together with other words, also appropriate translation and example sentences are given.

Another possibility is to see the words which derive from the current word or composed ones, as shown on Figure 6.

On the figures below are shown the texts list available in the Demo package of Mobile ELDIT for both languages – Italian on Figure 7 and German on Figure 8. One can see the group to which they belong in bold font and the name of few texts listed with bullets.

Fig. 7: Available texts (Italian)

Fig. 8: Available texts (German)

INSTALLATION AND SET-UP INSTRUCTIONS

WHAT SHOULD BE DOWNLOADED

To use Mobile ELDIT you have to download and install:

1. The sample m-ELDIT package from the following address: http://www.science.unitn.it/~foxy/MobileELDIT-Form.php
   The sample package contains three texts of three thematic groups in both difficulty levels (AB – more difficult, C – simpler) in both Italian and German languages.

2. A special virtual machine for your PDA, called ewe: http://www.ewesoft.com/
   You can see list of all supported devices and download the latest version from the EweSoft web site. I'm providing only

the ewe virtual machine installation for PocketPC, with which the system was tested at the following address: http://www.science.unitn.it/~foxy/mELDIT/Ewe143-CAB-PocketPC.zip

3. You also need to use a different browser - NetFront3. A trial version for PocketPC is available on the developer's web site: http://nfppc.access.co.jp/english/agree.html
   Here you can download the installation for PocketPC2002, with which the system was tested
   http://www.science.unitn.it/~foxy/mELDIT/NF31PPC2ARENR10D.ZIP

HOW TO INSTALL THE EWE VIRTUAL MACHINE

To install the EWE virtual machine on your device you should connect the device to your PC and use ActiveSync. In the zip file you have downloaded you should find the ewe installation (i.e. a .cab file) which is appropriate for your device processor type. You should copy this file and run it on the device, using File Explorer. Follow the instructions that appear on the screen. EWE virtual machine will be installed automatically and the .cab file itself will be removed from the device.

After finishing with the installation of the virtual machine go to the Programs folder on your device and open the EWE folder. Click on the ewe icon to activate the VM. You see a screen, similar to the one shown on the right.

For more detailed instructions and support see EweSoft web site:
http://www.ewesoft.com/

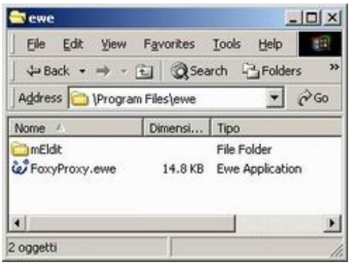
HOW TO PUT M-ELDIT PACKAGE ON THE PDA

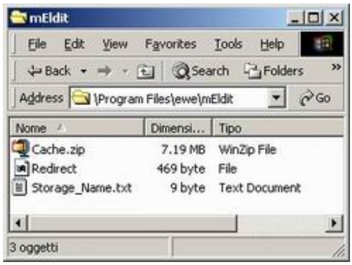
The MobileELDIT.zip file you have downloaded contains all the data of the demo package of Mobile ELDIT system.

1. Unpack MobileELDIT.zip in some temporary directory on your PC (e.g. C:\Temp). From the zip one directory called 'ewe' (no quotes) should be extracted.

2. On the mobile device, using File Explorer, put the folder 'ewe' (no quotes) in the folder Program Files.
   The result is: {On the PDA} \Program Files\ewe\

3. Now on the mobile device you should have ewe folder that contains a folder m-ELDIT and a file FoxyProxy.ewe like shown below.





! If you have an external memory on your PDA it is preferable that you keep the memory inside the slot while using Mobile ELDIT, so the system will do regular backups of the collected tracking data

For details on what is collected, see the FAQ: Why the proxy is needed?

You should enter the type of the memory you use in the following file:

{On the PDA} \Program Files\ewe\mELDIT\Storage_Name.txt

You can open it on the mobile device by simply clicking on it.

NOTE: On different devices, memory types and OS versions the name of the external memory will vary. Some possible names are: CF Card, SD Card, Storage Card, Scheda SD/CF, etc. You can see the correct name of your memory in the File Explorer on the mobile device. You can recognize it by the icon .

If different users will use the system with the same device, please read the instructions on how to set-up usernames.

HOW TO SET-UP USERNAMES

There are two modes to set-up user names:

1) *(probably better choice)* Set the user-name in advance and do not allow the user to change it.
2) Let the user choose each time his/her 'username'

For 1) before starting the proxy you should edit the file User_Name which you will find in:

{On the PDA} \Program Files\ewe\mEldit

It is a simple text file and can be edited directly on the device. The name might be actually a nickname, but in any case it should be a string with no spaces.

<u>*Example:*</u> AlbertoCattaneo or Alberto1

It's up to you to decide the username generation procedure ;)

Note: The procedure should be done only when the new user will start using the system, not when the content packages are changed.

For 2) When setting-up the NetFront3 browser (see step 2b on page 169) you should point as a homepage the page following:

http://www.mobileeldit.com/User_Change

instead of:

http://www.mobileELDIT.com/TextsList

This will make the system show the following screen every time the NetFront3 browser is

started. Thus the user will choose from 9 possibilities. This option is proper if the users are very responsible!!!

HOW TO SWITCH ON THE PROXY

The system uses a local (on the PDA) caching proxy, called FoxyProxy that should be located in the following directory:

{On the PDA} \Program Files\ewe

The proxy should be switched on. For doing this you should do the following steps:

1. Executing the FoxyProxy program by clicking on it;

2. Starting the proxy by pressing the "Start Proxy" button

3. You should see written on the screen what is shown on the picture on the right
** it might take about 1 min.*

4. Press Start Menu -> Today

**** Note that you should NOT press the OK button in the top-right corner, but directly open the Start Manu and choose Today. Pressing the OK button will actually switch off the proxy.***

HOW TO INSTALL AND SETUP THE NETFRONT BROWSER

After downloading the NetFront installation appropriate for your device you should run the .exe file and follow the instructions on the screen. To run the browser press the Start Menu on the device and choose Programs. Click on the NetFront icon (shown up) to start the browser.

When you first open the newly installed NetFront browser you should do the following:

1. From the 'Tools' menu choose 'Browser Settings'
2. In the 'General' tab:
   a. Uncheck 'Use cache'

   b. Press 'Home' button and in the newly opened window write as HOME page: http://www.mobileELDIT.com/TextsList

   Note: If more users will use the same device at the same time or consecutively please take a look at the instructions 'How to set-up Usernames' on page 165.

   c. Press OK button
3. In the 'Network' tab:
   a. Check the 'Use proxy' option

b. Write "localhost" (without the quotes) in the field on the left

c. Write 3128 in the field on the right (e.g. the port)

4. Press the OK button in the upper-right corner.

5. From the File Menu choose Home - this should open the starting page of the sample Mobile ELDIT package with the list of available texts (see the screenshots).

Note: To exit the browser you should use the File menu "Exit".

HOW TO CHANGE THE DATA PACKAGE

To change the content data package (the cache with new texts and related words) you need to:

1) Switch off the proxy and the browser
2) Delete the old package
3) Copy the new package
4) Switch on the proxy again

For step one the easiest way is to clean the memory from ALL programs, including the proxy and the browser. Please see the relevant HowTo on page 171.

Step two might be performed on the device, using the File Explorer (StartMenu -> Programmi -> Esplora file). Go to:

Dispositivo/Program Files/ ewe/mEldit

By click-and-hold on the Cache item you will get a fall-down menu from which choose Delete (Elimina).

Note: The step could be also performed from the desktop PC.

For step three you need either to connect the device to the PC, where you have the new content package or you have to use a memory card with the package copied to it previously.

In both cases you need to put the new package in

{Device/Dispositivo}/Program Files/ ewe/mEldit

where the old package stood. If necessary rename it, so its name is Cache.

Step four – follow the 'How to switch on the proxy' instructions.

HOW TO GET AND SEND THE TRACKING DATA

This procedure might be done at any time, but the most suitable two options would be either when new package is uploaded, or when the PDA will not be used anymore by the same user. The preferred option is the first one – on package change.

The tracking data is automatically recorded in log files and also backups are often done on the external memory. The files that are needed are:

1) From the memory card all the files with name:
   Backup_*.log
   Note: The files might be quite a lot (as number, not in size)
2) Two file from the folder
   {Device/Dispositivo}/Program Files/ewe/mEldit
   which have the following names:
   *_History.log
   *_Feedback.log
   The star (*) means that there is a varying text on this place.

I would prefer that from any device these files are copied separately into a folder with the name of the user on the desktop PC and zipped are send to me by mail.

Note: It is not that important not to mix up the files, as their names contain the information we need to split them, but some post processing time could be saved ;)

When you are sure that these files are safely copied on the PC please delete them from the device, both from the local and from the external memory.

HOW TO CLEAN UP THE MEMORY

From the Start Menu choose 'Impostazioni'.

In the System tab press the 'Memory' button and go to the third tab, which is 'Programmi in esecuzione'. A screen should be as shown on the figure below:

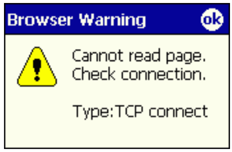
All unnecessary programs should be closed by selecting each of them (clicking on the name in the list) and then clicking on the 'Close' ('Termina') button.

For Mobile ELDIT system to work properly only the FoxyProxy and the NetFront3 browser are necessary. If the FoxyProxy is not available or is by chance switched off, please switch it on.

WHAT TO DO IF…

- ***THE SYSTEM OR THE PDA ITSELF WORKS VERY SLOW***
  - *probable reason*: Too many programs are started simultaneously and occupy big amount of memory.
  - *solution*: 1) Clean up the memory (see above)
- ***THE SYSTEM DOES NOT WORK***

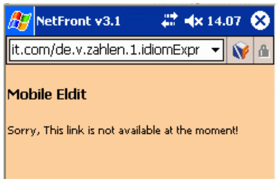
- *symptom*: Browser returns the following message:



- *probable reason*: the proxy is switched off. Might be because of an accidental action from the side of the user or an overload of the memory.
- *solution*:

1) Clean up the memory
2) Start up the proxy

- ***NO INFORMATION IS SHOWN***



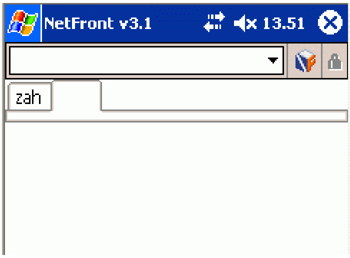
  - *symptom*: A strange web page is shown, saying something in English ;), as the one on the picture:
  - *reason*: The word you have requested is not available at the moment and can not be displayed.
  - *solution*: Nothing to be done… Just click on the back button and continue your study. I hope you will not meet this situation often.

- ***A FALL DOWN MENU APPEARS***
  - *symptom*: You can not follow the links, because a menu appears every time you try to (as shown on the picture):

  - *probable reason*: when you click-and-hold on touch-screen the system shows the context-menu, as a right mouse button click on a PC computer.
  - *solution*: Click somewhere outside the menu, so that it disappears. For following the links you need to do a short click (not to hold down) and wait for few seconds for the page to be displayed. While the browser shows a ro-

tating globe next to the address field (see the figure below) it downloads the page so you have to be patient.

- ***ADDITIONAL TABS IN THE BROWSER APPEAR***
  - *symptom*: You see multiple tabs in the browser window and you do not find the learning content anymore, as on the picture:



  - *probable reason*: When the system have shown you a context-menu (you click-and-held on the touch-screen) you unintentionally pressed the 'New Window' choice.
  - *solution*: Click-and-hold somewhere in the blank field and from the menu that will appear choose 'Close Window'.

KNOWN PROBLEMS

There are few known bugs that appear in the current version of the system that should be listed here:

- When using the NetFront3 browser version 3.1 there is a small problem displaying the special German and Italian letters (German umlauds: ä, Ä, ö, Ö, ü, Ü, ß; Italian – à, À, è, È, é, É, ì, Ì, ò, Ò, ù, Ù). After such letter a space is displayed, which in practice should not exist. The problem is due to the NetFront3 implementation where this letters are not correctly supported. As the developers are aware of the problem it is expected to be corrected in later versions.

- With some PDA devices, namely iPaq 3800 but probably can happen on other models, a sudden crash of the proxy was noticed that happens if the device is often switched off and on without exiting the started applications. Our suggestion is that a memory optimization is done automatically by the OS,

which is out of our control. In such case the proxy needs to be restarted. The problem will be easily noticed, as on the first request done by the user the browser will give a message that no response was received from the server.

- A significant problem that should be mentioned, though described in the Pocket PCs user manual, is that the battery of Windows based devices discharges quite fast. When a device is frequently used it discharges in 1-2 days, but the main problem comes from the fact that even when not used the battery discharges in about a week time. The discharged device "forgets" the software installed by the user and all user's data. This leads to the necessity to do backups of all important data on an external memory quite often. It is also very inconvenient as all the programs that were installed should be re-installed.

FAQ

- **Why should I use NetFront, instead of IE browser?**
  The reason to use other browser, not IE is that IE does not send requests to the local proxy when no Internet connection exists. This does not allow the local proxy to provide offline access to the learning material.

- **Can I use other browser, instead of NetFront3?**
  Yes. Other browsers could be used, but the system is not tested with other. There is a requirement that the chosen browser allows the usage of local proxy and the browser should be set-up properly, i.e. to send the requests to the localhost proxy on port 3128. A possibility could be to use Minimo - Mozilla for Pocket PC, which could be downloaded at: http://www.mozilla.org/projects/minimo/
  However the last version we have checked (v. 0.0009) still had some problems with user interface on the devices we were using and we were experiencing much bigger delays, comparing

with NetFront browser. However it seams that in a short time Minimo will be the browser of our choice.

- **Why the proxy is needed?**
  Mobile ELDIT works offline, utilizing a caching proxy, called FoxyProxy, thus does not require Internet connection. In fact the proxy catches the requests of the browser and extracts the needed data from the cache. In case that the requested entry is missing it informs the user. The proxy also collects log files of the requested entries with associated request times. This is needed for the research on the hoarding problem (for details see http://www.science.unitn.it/~foxy/papers.html).

- **Can I browse the Internet through NetFront browser or it is only for utilizing Mobile ELDIT?**
  NetFront browser is not especially for utilizing Mobile ELDIT. Though because our system is still under development in order to use NetFront for browsing the Internet (i.e. to access pages that are not part of Mobile ELDIT) you should set up NetFront NOT to use the proxy FoxyProxy.

- **I don't have my own device. Can I use Mobile ELDIT anyway? Can I borrow a device? How? Where?**
  Mobile ELDIT can be found also at the "Mediateca Multilingue" at Bolzano and Merano. Few PDA devices are available for use and for loan to the adult members of the Mediateca. http://www.provincia.bz.it/cultura/bilinguismo/multilingue/mediateca_ebook_i.htm

  You can get more information at:

  Merano:
  Piazza della Rena, 10
  "Palazzo Esplanade", I° piano, entrata piazzetta interna
  39012 Merano
  Tel. 0473 252264/63; Fax 0473 252265
  meranolingue@provincia.bz.it

  Bolzano:
  Via Cappuccini 28
  39100 Bolzano
  tel. 0471 300789; fax 0471 303406
  centromultilingue@provincia.bz.it

- **Who should be contacted if further information or help on Mobile ELDIT usage is needed?**
  For any further information, help or comments, please contact the author in one of the following ways:

Work Address: via Sommarive 14
C.A.P. 38050, Povo (TN), Italy
Office Phone: +39 0461 88 2076
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E-mail: trifonova@science.unitn.it
www: www.science.unitn.it/~foxy/

Appendix B

Mobile Learning can be viewed from various angles and research can be performed in different directions. One very important and innovative one is on providing context-aware services to the learner. At the beginning of the thesis some work was done on exploring location-dependent services in mobile learning domain. As this work is not in the main focus of the thesis, but is still related to the thesis we find suitable to report it as appendix.

Context dependent services in an m-learning environment: the printing case.

1. Introduction and Related Work

"m-learning" is one of the successful buzzwords of the beginning of the millennium. It combines the promises of two very promising fields: e-learning and mobile computing. E-learning is growing at a very fast rate: nowadays most universities have at least some degree of support for e-learning, companies are investing in the field, and the need for continuous education pushes for e-learning solutions. On the other hand it is likely that mobile telecommunication will continue to grow and to add new services. Competing and complementary wireless technologies like wireless LAN, Bluetooth, GPRS and UMTS will multiply potential handheld applications. IDC forecasts that 63 millions handhelds will be sold by 2004, and that approximately 38% of them will be smart phones, integrating PDA functionality with features for communication. Most mobile clients will support Java (J2ME) making it easier and less costly to develop portable applications. Given such scenario, forecasting the success of m-learning seems to be an easy bet. It is more difficult to understand in detail how m-learning will help reaching the goals of a better learning, and how it will be different from the rest of e-learning. According to

the literature, see the conclusions of the 'State of the art' section (2.3) but also [117] and [95] successful m-learning will be characterized by the following properties:

- *5 minute value*: the ability to use small fragments of time (e.g. waiting time) for learning (e.g. doing quizzes, using a discussion forum, communicating, reading material);
- *Simplicity*: the limited display and input capabilities of the mobile devices make it difficult to use rich (e.g. complex and multimedial) documents using a PDA-like interface: it is therefore not useful or practical to transpose a power-point presentation on a PDA;
- *Context dependent information*: the dependency can be relative to:
  - location context; i.e. the system knows the location where the learner resides and adjusts to it;
  - temporal context; i.e. the system is aware of time dependent data;
  - behavioral context; i.e. the system monitors the activities performed by the learner and responds to them adjusting its behaviour;
  - interest specific context: i.e. the system modifies its behaviour according to the user's preferences.

Examples of context-dependent systems (although not related to m-learning) are:

- Tourist information systems, like GUIDE [17] and CYBERGUIDE [2]: these systems offer information to tourists, taking into account their current location.
- Context-aware messaging systems that trigger actions according to a specific context, like the ComMotion system [70] which links personal information to locations and generates events (e.g. sound or message boxes), when a user moves to a certain location. Other such systems are CyberMinder [24] and lcron [37]: they allow the user to define more complex conditions, like time-and-location dependent conditions.
- General utilities, like "Friend finder", "GeoNotes", "BusLocator" [75]

We experiment with such requirements, addressing a simple task that is often necessary in all e-learning environments, and that is in general taken for granted: the ability to print a document. This quick, simple task (if performed in a non-mobile environment) becomes less trivial when performed from a mobile device, like a palmtop/laptop equipped with a wireless-LAN card. We show that this apparently trivial task contains elements that constitute a template for other problems that can be experienced when approaching e-learning from the mobile side.

2. The Problem and Possible Solutions

In few words the problem we experiment with can be expressed this way: “Printing on the nearest suitable printer”.

Let’s compare the non-mobile and mobile case of the printing process. In common, one should be able to print from any application which actually uses the APIs of the operating system (OS). There is usually a default printer, local if exists, but more often the printer is on the network and the OS is managing the network interface and passes the job to the printer when needed. The OS has to be able to “talk” the particular printer’s “language” in order to do the task correct (i.e. a specific printer’s driver should be installed).

If the computer is mobile some more conditions should be added – location-time-dependant data should be considered. Based on this data and possibly to some other preferences, like user’s access rights over a certain printer or pages limitations, a decision should be taken. This could be done locally or on an external resource – a server. The system should find which is the most convenient for this user and accessible in that moment printer; inform the user about the choice, possibly giving him the possibility to modify this choice. Finally the document should be printed, optionally allowing the user to monitor the status of the printer queue.

“Printing on the nearest suitable printer” contains elements that can be found in many other mobility-related problems. What makes the printing problem so prototypical, as we shall dis-

cuss in a later section, is the fact that printing is a service (and can be used from any application) and it uses services (those provided by the operating system). There are various architectural choices that can solve the printing problem. We shall briefly discuss them, outlining advantages and disadvantages of each of them.
The first step is collecting context information. In order to find the “closest” printer we need to know where the user/device is, i.e. their physical position. But then occurs the problem that the “nearby” printer could not be always reachable (some room might be locked at night or during week-ends). The behavioural information is also important. Knowing what the user is currently doing and what applications is using at that time could provoke the usage of different printer (a black and white printer if the user is reading a text-only document or a colour printer if the user is looking at pictures). Preferences might involve opting by default for cheaper services at expenses of print quality, or vice versa. Also the knowledge about “who the user is” is important (there might be different restrictions on printers’ usage for teachers and for students or limit over the number of printed pages).

The second step is to choose the resource (printer) that best suits user’s needs, taking in account the context information. Therefore, the location info and characteristics of all printers must be known to the party that takes the decision. As mentioned before the choice could be made locally or on the server.

If we consider a local case then all the information needed for the decision-making should be stored on the device. In a limited mobility the data might not be massive and might not endanger the availability of the device’s memory. One might also imagine that when moving to a different environment (e.g. to another building) the mobile device could discard all the info regarding the previous environment, and download the info relative to the present surroundings. In this way though the system might omit some real time info, like the printers’ queues at the current moment, thus producing poor solution (it is probably better to walk a few more steps to an empty printer, that quickly reaching a busy one). Another issue has to be considered. To perform printing

from a device to a certain printer the device needs a driver for that printer. A desktop computer can have installed on it drivers for all supported by the system/network printers, which for a mobile device is not suitable solution. One could think of downloading on demand the needed drivers, but sometimes installing a driver requires rebooting the machine, so also this solution is not sensible.

A second possibility is that info about the printers is kept on some server: the mobile client could contact the server passing its own context info, and getting back the indication of the chosen printer. After all, this is what is typically done in a multi-user OS, where printers are never directly accessible by the users (to stay away from nasty concurrency problems), and has the advantage of enabling accounting and permission checking. The main drawback of having a centralized server is the scalability of the solution, in terms of performance (the central server becomes a bottleneck), reliability (the server becomes a critical single point of failure) and geographic scale (it makes no sense of thinking of a central server that knows about all printers in town). One can overcome these weaknesses in a standard way, i.e. by having a federation of servers (each being responsible for a sub-region, and being able to forward requests to other servers) with some degree of replication.

There are two possible ways to ask the server to print a document: one is to pass to the server the current version of the document, and the information about the application that is using the document, and the other is to pass to the server a printable device-independent version of the document (such as a postscript file). The first solution requires the server to carry all possible programs and to recognize all possible file formats, which makes this option inconvenient. To achieve the second is much easier – one needs a postscript printer driver on the mobile device side, which produces a Postscript file, and then sends this file to the server. On the server side the file is printed on the chosen printer. It is possible to print Postscript files also on non-Postscript printers, e.g. using (on the server) the Ghostscript program that is available for different operating systems.

At this point, what we call "printing" on the mobile device actually means 1 - "print the document to a postscript file", 2 - "pass to the server the context information and the generated file", 3 - "have the server choose the printer, send the postscript file to it, and pass back the info about the chosen printer". One last problem remains open: all this should happen when the user chooses the "print" menu item. This means that one should write a (pseudo) printer driver that, when invoked, performs all these actions. This is certainly possible, although it requires digging in OS-dependent technical details.

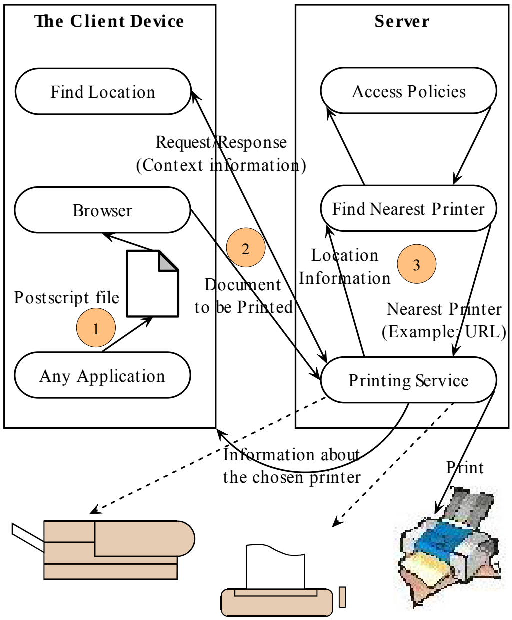

Figure 44: The printing process

We implemented a little less convenient but more immediate solution in which we perform the following steps: the user generates a postscript file (as we described it earlier), then he/she contacts explicitly through HTTP to the server, using a web-browser. The server provides a form, where the user points to the file and sends it to the server. An active component (e.g. a servlet) than opens a

socket to the client and collects the context information. On this basis the server finds the nearest printer, prints the document and informs the user of the choice, together with explanation where the printer is located. The information is returned again in the browser via HTML page. Of course, we have here implied that the mobile system is able to provide a service via socket to pass the context-dependent info. As an alternative, one could pass all this info through HTTP. Figure 1 describes the whole process.

As far as the positioning system is concerned, we note that to implement a location-aware system we need a proper positioning system and there are many possible solutions provided in literature. Different technologies are developed for determining the user's location. Lots of research had been done and systems had been made for automatically locating people, equipment, etc ([110]; [112]; [111]; [78]; [40]; [39]). These different systems address different problems and so the location-sensing in each of them has different parameters, properties and accuracy. Some of them are suitable only for finding the position of the device when outdoors (Global Positioning System GPS), while other only work indoors. Additional infrastructure and/or equipment is necessary for most of the location determining systems (i.e. Active Badge and Active Bat systems require special tags and basis/stations; in the GPS case the infrastructure is already in place, so that it can be given for granted, but the user is required to have additional hardware on the client machine - a GPS receiver).

In general more appropriate would be a system that does not require additional hardware or infrastructure. In our system we use the IEEE 811b network that is already in place so it requires only adding a software layer. A small module on the mobile device connects sequentially to three or more access points in the wireless local network and measures the signal strength (the wireless network card acts as a sensor). Note that in a conceivably wireless networked city, such method would work indoors and outdoors. The results of the measurements are used to determine the position. There are different ways of doing this. With one of the methods called regression the position could be returned in

physical coordinates (x, y, [z]) and in another (classification) as a more semantically meaningful (symbolic) expression, like floor and room number or “Professor X’s office”. Depends on the method chosen the accuracy varies. The research shows [7] that the average error percentage in this second method is lower, thus it is more reliable.

The position-determining system that we use comes in two variants: the first returns raw data (physical coordinates); the second returns a semantic description of the location. The second option we find more suitable for our goal because we can explicitly take account of the local topology (meaning walls, aisles etc.).

In a system, where more than one positioning systems will be used one can think of introducing a semantic server, which translates data from the format used by the device (GPS, WLAN, Bluetooth) into format, proper for the server that offers the printing service.

We experimented with a system [6] based on the strength of the IEEE811b signal coming from different antennas, that uses available hardware and infrastructure, and therefore requires only adding a software layer. In a conceivably wireless networked city, such method would work indoors and outdoors.

3. Generalization

We have seen that the printing problem can be mapped on a more general one, where the focus is on providing some context-dependent service, while using basic services provided by the infrastructure (e.g. by the OS, or by a Learning Management System).

The idea is to insert a software layer between the service requestor and the service provider. As we discussed, such software layer should in general refer to an external server for at least two reasons: the mobile component cannot be aware of all possible settings that are available in different places, and the optimal choice might depend by factors that could be dynamic, and therefore unknown by the mobile component. The external server must obtain context data from the requestor. At this point two choices

are possible: either the server fully provides the customized service, or it provides a "meta-service", i.e. it only identifies the best option and then passes this information back to the requestor. The requestor then performs the actual customized service. In some cases (like in the printing problem) this last solution might be highly unpractical; in other cases however it might be a viable solution, and might even be preferable since it diminishes the workload on the server. As we have seen, implementing this middleware in a seamless way can require digging into technical details of the infrastructure (e.g. of the OS). In the particular case of the printing, it required writing (or at least modifying) a device driver, that is not a trivial task. In other cases, like for instance in the case of a service provided by a Learning Management System, it might mean entering in the (possibly proprietary) code of the infrastructure providing the service: a possibly prohibitive task. In such cases one can fall back to a less convenient, two step process: through the notion of a stub one would then use a local instance of the needed service (i.e. one might have an actor on the server that asks for a local service on behalf of a remote, mobile user).

Appendix C

List of publications

A major part of the work for this thesis has been published in peer-reviewed journals, conferences and workshops in the area of computer supported learning and e-learning. Here the list of the papers is given, ordered by publication date.

- Trifonova A., Ronchetti M. (2006). Hoarding Content for Mobile Learning. *International Journal of Mobile Communications (IJMC), Vol. 4, No. 4,* pp.459–476
- Trifonova A., Georgieva E., Ronchetti M. (2006). Has the Time for University's Mobile Learning Come? Determining Students' Readiness. *(submitted in) Journal of Educational Technology & Society endorsed by IEEE Technical Committee on Learning Technology.*
- Kennedy, I.G., Fallahkhair, S., Fraser, R, Ismail, A., Rossano, V., & Trifonova, A.(2005). A Simple Web-based Adaptive Educational System (SWAES). *(to appear in)* Special issue on Modeling and Simulation of *International Journal of Technology, Instruction, Cognition and Learning (TICL)*
- Trifonova A., Knapp J., Ronchetti M. (2005). E-learning versus M-learning: Experiences, a Prototype and First Experimental Results. *Proc. of World Conference on Educational Multimedia, Hypermedia and Telecommunications (ED-Media 2005)*, June 27-July 2, 2005, Montreal, Canada. pp. 4751-4758.
- Trifonova A., Ronchetti M. (2005). Hoarding Content in an M-Learning System. *Proc. of World Conference on Educational Multimedia, Hypermedia and Telecommunications (ED-Media 2005)*, June 27-July 2, 2005, Montreal, Canada. pp. 4786-4794.
- Trifonova A., Ronchetti M. (2005). User Behaviour Observations for Supporting Offline Delivering of Learning Materials in a Mobile System. *Proc. of World Conference on Educational Multimedia, Hypermedia and Telecommunications (ED-Media 2005)*, June 27-July 2, 2005, Montreal, Canada. pp. 1520-1527.
- Trifonova A., Ronchetti M. (2005). Hoarding Content in M-Learning Context. *Proc. of PerEL 2005 - Workshop on Pervasive eLearning, held in conjunction with the Third IEEE International Conference on Pervasive Computing and Communications (PerCom'05)*, March 8-12, 2005, Kauai Island, Hawaii. [IEEE Computer Society Press 2005, pp. 327-331.
- Trifonova A., Ronchetti M. (2005). Prepare for Bilingualism Exam with a PDA in your hand**s**. *Proc. of the International Conference on "Methods and*

Technologies for Learning" (ICMTL'05), March 9 - 11, 2005, Palermo, Italy, WIT Transactions on Information and Communication Technologies, vol. 34, Edited by G. Chiazzese, M. Allegra, A. chifari & S. Ottaviano. pp. 343-347.

- Judith Knapp and Anna Trifonova (2005). Mobile ELDIT: Language Learning on the Go!. *Academia (EURAC's Science Magazine), Vol 37, March 2005*. Edited by Sigrid Hechensteiner & Stefania Coluccia, pp.21-22
- Trifonova A., Ronchetti M. (2004). A General Architecture for M-Learning**.** *International Journal of Digital Contents, Vol. 2, No. 1*, Special issue on "Digital Learning-Teaching Environments and Contents". *Proc. of the II International Conference on Multimedia and Information and Communication Technologies in Education (mICTE2003)*, Badajoz (Spain), December 3-6, 2003, Edited by Antonio Méndez-Vilas and J.A.Mesa González. pp. 31-36.
- Trifonova A., Ronchetti M. (2004). A General Architecture to Support Mobility in Learning. *Proc. of the 4th IEEE International Conference on Advanced Learning Technologies (ICALT 2004 - "Crafting Learning within Context")*, August 30 - September 1, 2004, Joensuu, Finland, pp. 26-30.
- Trifonova A., Knapp J., Ronchetti M., Gamper J. (2004). Mobile ELDIT: Transition from an e-Learning to an m-Learning System. *Proc. of the World Conference on Educational Multimedia, Hypermedia and Telecommunications (ED-MEDIA'04)*, June 21-26, 2004, Lugano, Switzerland, pp.188-193.
- Ian G. Kennedy, Sanaz Fallahkhair, Veronica Rossano, Anna Trifonova, Antonella Grasso, Sabine Graf, Jean-Claude Ziswiler, Ricardo Fraser (2004). Simple Web-based Adaptive Learning Technology. *Learning Technology newsletter, Vol. 6, Issue 4, October 2004*. Publication of IEEE Computer Society, Technical Committee on Learning Technology (TCLT). pp. 78-83.
- Trifonova A., Ronchetti M. (2003). Where is Mobile Learning Going?. *Proc. of the World Conference on E-learning in Corporate, Government, Healthcare, & Higher Education (E-Learn'03)*, Phoenix, AZ, USA, Nov. 7-11, 2003. pp. 1794-1801.
- Colazzo L., Molinari A., Ronchetti M., Trifonova A. (2003). Towards a Multi-Vendor Mobile Learning Management System. *Proc. of the World Conference on E-learning in Corporate, Government, Healthcare, & Higher Education (E-learn'03)* , Phoenix, AZ, USA, Nov. 7-11, 2003. pp. 2097-2100.
- Alfio Andronico, Antonella Carbonaro, Luigi Colazzo, Andrea Molinari, Marco Ronchetti and Anna Trifonova (2003). Designing Models and Services for Learning Management Systems in Mobile Settings. *Proc. of Mobile and Ubiquitous Information Access: Mobile HCI 2003 International Workshop*, Edited by Fabio Crestani, Mark Dunlop, Stefano Mizzaro, Udine, Italy, September 8, 2003, Springer LNCS vol. 2954/2004, pp. 90 - 106.
- Trifonova A., Ronchetti M. (2003). Context-Dependent Services in an M-Learning Environment: the Printing Case. *Proc. of IADIS International Conference e-Society 2003*, Edited by Palma Dos Reis A., Isaias P., Lisboa, Portugal, 3-6 June, 2003. pp. 635-638.